Our Energy Options

Seven important aspects of electric power planning examined by well-known authorities

Foreword by
Arthur Porter
Chairman, Ontario Royal Commission on Electric Power Planning

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Foreword

Arthur Porter

Arthur Porter, the chairman of the Ontario Royal Commission on Electric Power Planning, is professor emeritus of industrial engineering at the University of Toronto. Formerly, he was professor of electrical engineering at the University of London and then dean of engineering at the University of Saskatchewan. He is a fellow of the Royal Society of Canada and a member and former chairman of the Canadian Environmental Advisory Council.

Since its inception in July 1975, the Ontario Royal Commission on Electric Power Planning has been particularly conscious of its educational role and responsibilities. The sheer breadth of the terms of reference, embracing as they do many aspects of social, economic, environmental, and technological planning for the future of the province, has called for understanding and perception far transcending our original conceptions. As the Commission's work has evolved, not only have we contrived to develop learning environments of a variety of kinds (public hearings, workshops, symposia, and seminars) for the benefit of the public, the Commission, Ontario Hydro, and the government, but our educational endeavours, through our Outreach program, have penetrated into the schools and colleges.

The need for education in energy and associated subjects was originally stressed during the inaugural public meeting of the Commission held in the Richard Ivey School of Business Administration, University of Western Ontario, when a Grade XIII student strongly advocated the development of appropriate school curricula in such fields as electric power and energy conservation; he mentioned especially the urgent need for suitable reading material. It was this timely intervention which sowed the first seed which ultimately gave birth to this collection of essays. But seeds of this kind, and indeed of all kinds, need fertilization in the form of financial support. And it is a particular pleasure to record that The Richard Ivey Foundation, through the good offices of its secretary, Ross Willis, provided this support.

Shortly after our inaugural meeting, recognizing that the Royal

Grade IV pupils of Baythorn Public School, Thornhill, present a brief to Dr. Arthur Porter on May 24, 1977, in the hearing rooms of the Royal Commission on Electric Power Planning. With the children on that occasion were their teacher, Mrs. L. E. Ayres, and some of the parents. (Source: Ontario Hydro)

Commission could play a significant role in the cultural and social life of the province and the nation, the Foundation contributed a very generous grant to be used in any way which the Commission thought to be appropriate. The decision to utilize this grant for the preparation of a series of essays in the field of energy, with perhaps special emphasis on electricity, was an obvious one. The topics were chosen by the Commission. We subsequently invited well-known authorities in the corresponding subject areas to write the essays, which appear in this volume.

Each of the authors accepted the invitation with alacrity and I am sure that their reflections, perceptions, and prognostications concerning key aspects of the energy future of our provinces and nation, and concomitantly the future life-styles of each one of us, will contribute significantly to the continuing debate. The fact that the essays address the social, health, environmental, and in some degree the economic, rather than the essentially technological, issues associated with energy resources and their utilization is not coincidental. From the point of view of most students and certainly of the lay public, the major concerns fall into these categories. I should stress, however, that the views expressed in the essays do not necessarily coincide with those of the Commission.

The Commission gratefully acknowledges the support of The Richard Ivey Foundation, the dedication of the authors, and the editorial expertise of Tom Fairley. All of these contributions made this volume possible. We hope it will serve the educational purpose originally identified by the London high-school student.

ARTHUR PORTER
Chairman
Royal Commission
on Electric Power Planning

Efficient Utilization of Energy

Walter Murgatroyd

Walter Murgatroyd holds the chair of thermal power at Imperial College and is a former chairman of nuclear engineering there. One of his main interests is energy policy, particularly those aspects of it that have to do with the utilization of energy. His career has included research for Rolls-Royce on jet propulsion and feasibility studies of a reactor system for the U.K. Atomic Energy Authority.

Canadians have the world's second largest per capita consumption of energy, and, in fact, consume more electricity per capita than their neighbours in the United States. A number of factors have contributed to this situation, among them being a high standard of material comfort in a relatively hard climate and the distribution of the population over a wide area coupled with the almost universal use of the automobile. The large renewable energy resource in the form of hydro power and the presence of large deposits of all kinds of fossil fuels led to a cheap-energy policy that has served the development of the country very well.

Governments, in Canada and elsewhere, have adopted a relatively *laissez-faire* attitude towards energy policy. When they have wished to influence energy matters, they have acted at the supply end. Their principal concern has been to ensure that reliable and economic supplies were available to meet the national demand, and that the nation retained some control over its own energy resources. To a great extent, they have left the users free to select the kinds and quantities of energy they wished to consume, provided, of course, that they were willing to pay for them. For example, until very recently, taxes on fuels have more often than not been regarded as a source of revenue rather than a way of influencing energy utilization.

Experts are generally agreed that in the coming decades there will be major changes in our energy supplies, although opinions differ on the details and the timing. As energy consumers, our fundamental requirements are for services such as heat, light, and motive power, rather than for the oil, coal, uranium, hydro power,

and so on, that produce them. There are many alternative routes by which our requirements can be met in the future, routes that differ in the amount of primary fuel and capital they require and in their environmental effects. A sound and acceptable energy policy must embrace the energy inputs to the community and the service requirements of the users, as well as the complex operations by which one is transformed into the other.

The energy industry has always had to live with a major problem: consumer demand can change quickly, whereas the infrastructure necessary to supply it requires a long time for planning and construction – more than seven years in the case of nuclear power stations. Thus, the energy-supply industry has had to base its planning on long-term forecasts of an uncertain demand, in which errors can lead either to unacceptable shortages of energy or to under-utilization of expensive equipment. This problem could be magnified in the future if additional uncertainties arise about the availability and cost of the various basic fuels. It will become increasingly difficult for governments to avoid guiding or even controlling the consumer's choice among the different forms of energy he purchases. The extent and timing of this guidance could depend greatly on the awareness of all of us as consumers to the interaction between our energy demand and our energy resources, and on our responsiveness in our personal and professional lives to the changing pattern of energy supply.

My purpose here is to present some information about the ways in which we now utilize our energy, and some observations on the present effectiveness of our use of energy and the role we as energy users can play in shaping future energy policy. But before I go into the details of our use of energy I must deal with some important general matters.

Energy and Power

It is important to distinguish between "energy" and "power". Although "power" is often used loosely to mean electricity, the engineer and the scientist use it to indicate the rate of flow of any kind of energy. (This is the sense in which I will use it, except that I will use "power station" to mean electricity generating station.) For example, a gas cooker operated half-on for two hours will consume as much energy as it would full-on for one hour, but the flow of

Looking north over Toronto from the roof of the Harbour Castle Hotel – illustrating our dependency on electricity. (Source: Ontario Hydro)

power into it in the second case would be double. Electrical power is often measured in kilowatts and electricity energy in kilowatt-hours, the kilowatt-hour being the amount of energy consumed when a power of one kilowatt is switched on for one hour, or two kilowatts for half-an-hour, or 10 kilowatts for six minutes. Thermal energy (or any other form of energy) could also be measured in kilowatt-hours, but in North America it is usually measured in British Thermal Units (1 kW.h equals 3,412 BTU).

Power levels are important, because when we demand that energy should be available to us – in our homes, for example – at a

certain power level, the capacity of the wires to the house must be designed to handle this level, even though we may use power at that level infrequently and then only for short periods. In the case of electricity, in particular, since it cannot be stored economically and must at all times be generated at a power level that matches the demand, the supplier has to plan and construct generators, transformers, and transmission and distribution networks large enough to supply the expected maximum power demand, even if that maximum only occurs for short periods. It is clear that the more uneven the demand on a plant, the less efficient will be the use made of the equipment, and this will lead to more expensive energy because it will mean fewer kilowatt-hours over which to spread the interest and capital charges, which are fixed.

The effective use that is being made of the capital invested in a system is measured by what is called the "load factor" – the ratio of the average level of supply over a given period to the maximum use possible. (For example, the load factor of Ontario Hydro in 1975 was approximately 0.66.) The load factor is becoming increasingly important from the point of view of the user, because there is a marked trend towards the use of more and more expensive techniques for generating electricity. The growing use of nuclear stations is an example of this, and, if fusion reactors prove feasible, they will probably continue the trend. Also, the many techniques that are available to us for using sources of clean renewable energy, such as solar radiation, winds, waves, and tides, tend to be capital-intensive and their future economic potential will depend greatly on whether high load factors can be attained by getting users to spread their demands more evenly over the day, the week, and the year.

Conservation

In the last few years we have all been exhorted to conserve or to save energy. "Conserve" and "save" are often used indiscriminately, and, indeed, there are no accepted definitions that distinguish clearly between these two words in referring to energy. Of course, we can use less energy by doing without adequate lighting or house-heating, or by walking instead of using an automobile. Acts of this kind may be called "saving"; they involve a change of life-style and will not be discussed here. However, if

we can do essentially what we want to do in a way that uses less energy than before, we can say that we are "conserving" energy. Good examples of conservation are the installation of double windows instead of single windows on houses, and more efficient drive mechanisms for lathes.

In most situations, a capital outlay is required to conserve energy – storm windows and doors, for example, or better thermal insulation in a house or on a steam pipe. This capital is spent on additional materials, some of which may also be in short supply; we are then simply trading off one resource for another, and this may not always be desirable. Moreover, the extra materials may require a considerable amount of energy to produce, so that when this has been allowed for the over-all amount of energy conserved is not as great as it at first seems.

Sometimes, when a user calculates the interest he will have to pay to borrow extra capital, or the interest he must forego if he spends some of his own capital, he decides that a certain conservation measure is not worth while, although in many cases the decision not to go ahead does not coincide with the national interest. This can happen, for example, when interest rates on personal loans are high, or when taxes on materials discourage people from taking energy-conserving measures. It is important to recognize this and to provide appropriate incentives, so that, when an energy-conserving measure that an individual contemplates is clearly of benefit to the community, it is also seen by the individual as a benefit to him.

It is frequently reported that certain conservation measures are not carried out because of legal and institutional barriers. In some countries, for example, there seems to be a reluctance on the part of utilities to collaborate rationally with industries which, by their nature, could generate electricity locally, and very efficiently, and sell it to the utility: constraints of this kind, where they can be clearly identified, should not be tolerated by the public.

Heat and Work

Although energy is put to a wide variety of end uses, most of it is used to provide either heat or work. Examples of the latter are numerous: automobile engines, refrigerator motors, cooling fans. It is essential for an understanding of energy utilization to

appreciate some of the basic distinctions between heat and work that are imposed by the laws of thermodynamics. The transformation of work into heat is easily accomplished and can in theory be carried out with an efficiency of 100 per cent – the action of an automobile brake, for example. The transformation of heat into work is a much more expensive and less efficient process and one that usually requires an engine of some kind, for which the second law of thermodynamics sets an upper limit of efficiency. The fraction of the input of heat that is not converted into work is rejected at a lower temperature, and the theoretical efficiency depends on the temperatures at which heat is supplied and rejected. A high supply temperature and a low rejection temperature are both favourable to a high efficiency.

Except for hydro energy, which is a form of work, practically all of our supplies of work are produced by generating heat from fossil or nuclear fuel and then transforming the heat into mechanical work in, for example, a steam turbine or an automotive engine.

In order to maximize the conversion efficiency, the transformation equipment is usually designed to reject its heat at as low a temperature as possible. This is the case with most large fossil-fuelled and nuclear-fuelled power plants, and it results in such a low temperature of rejection that the heat is virtually useless for other purposes and must be regarded as wasted.

The transformation of fuel into work may take place at the final-user end, for example, in a power mower or an automobile, or it may be carried out remotely, the work-energy being transmitted by a suitable means. It used to be common to transmit work over short distances (throughout factories) by pulleys and belts that operated individual machines, and over longer distances by the use of water under high pressure in pipe networks. An extensive hydraulic energy system of this kind was built in London in the 19th century, before that city had an electricity distribution network. It was operated by a number of steam turbines and the work-energy was used to operate machines, to power elevators, and to activate, among other things, Tower Bridge. The network was damaged severely in World War II but is still in use today. Modern hydraulic systems, using oil instead of water, are in widespread use in aircraft, in naval vessels, and in some industrial situations where they have significant advantages over electricity, but electricity is by far the most widely used medium for transmitting work-energy, particularly over long distances, for which it is unrivalled.

However, electricity is a very costly form of energy to produce and transmit. It requires a much larger capital outlay, and it takes two or three times more fuel to produce than is needed to produce an equal amount of heat energy directly from a fuel. In principle, therefore, we should try to avoid using electricity simply for heating. In practice, of course, other matters influence our actions, prinicipally the convenience of electricity and the fact that it can be generated from fuels that are unacceptable for residential use, i.e., crude oil, coal, and uranium.

Where Does Our Energy Go?

Figure 1 is a simplified chart of the approximate energy flows in Ontario in 1973. It shows how the primary energy sources – oil, natural gas, coal, uranium, and hydro electricity – flow to the four user-sectors – transport, industrial, farm and residential, and commercial. (The commercial sector includes all uses that are not included in the other sectors, such as street lighting and military and municipal uses.)

The oil-based energy flow is very complex since it involves the conversion of crude oil into secondary fuels, some of which are also imported and exported. The chart does not show these complications. The figure for oil input is recorded simply as the sum of the outputs, and the losses and changes in stock are not shown. The most important use of oil is, of course, in the transport sector.

Approximately 90 per cent of the natural gas is burned to supply heat to one of the final-user sectors, and the remaining 10 per cent is used to generate electricity. The large proportion of gas used by industry is typical of North America, where its low price has encouraged industry to burn it. In Europe, even in countries such as Holland and the U.K. where there is a large indigenous supply, the policy has been to conserve gas for use in homes, because its cleanness and ease of control make it highly suitable for heating and cooking, and to encourage industry and the electricity utilities to use fuels that are not as suitable for residential use.

The use of coal is split about evenly between power stations and industry. Of the industrial half, only about 5 per cent is burned directly as coal, and the rest is used in the metal-smelting and gas industries, where it serves as a combination of fuel and chemical reactant and emerges as coke, coke-oven gas, and blast furnace

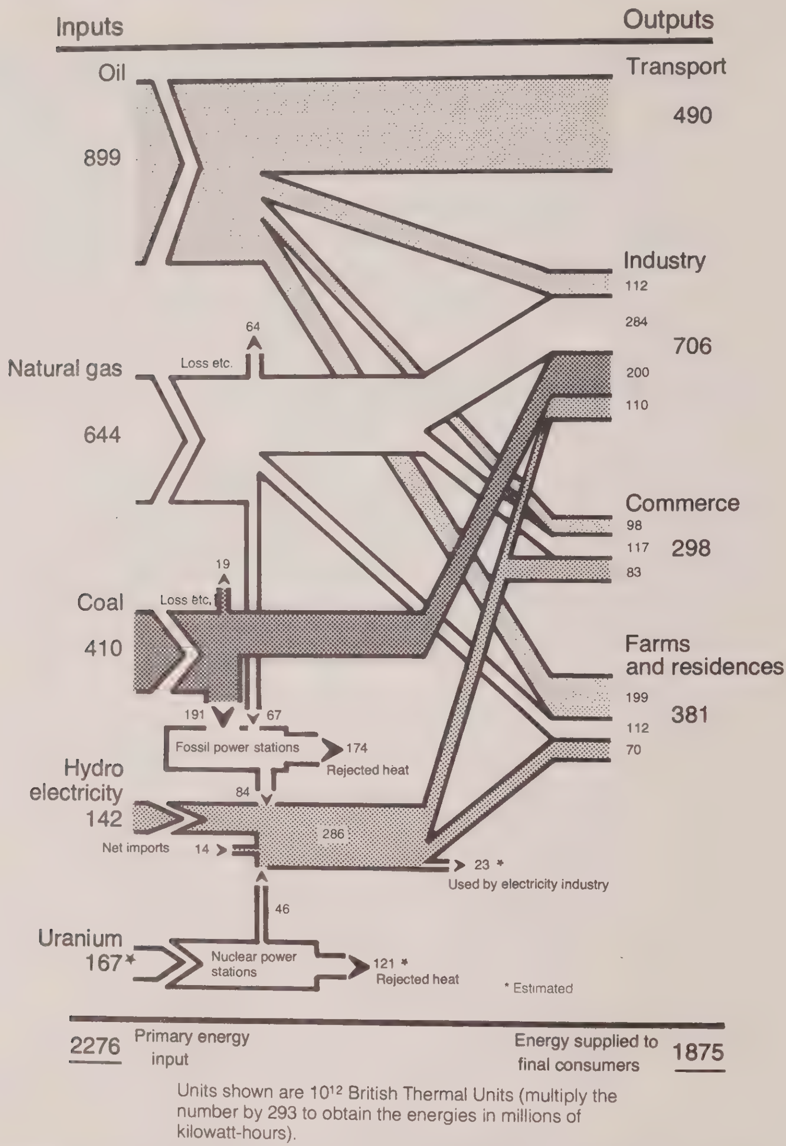


Figure 1. Approximate energy flows in Ontario in 1973, showing how the primary sources (inputs) flow to the user sectors (outputs). (Sources: Statistics Canada and Ontario Hydro)

gas. The cost of distributing coal widely in small quantities, and the difficulties of burning it efficiently and cleanly except in large furnaces, has favoured its use in power stations and large industrial undertakings rather than in residences.

Approximately 52 per cent of the electricity used in Ontario is generated in hydro-electric stations, mainly (nearly 90 per cent) by Ontario Hydro. The remaining 48 per cent is produced in thermal power stations, two-thirds of it from fossil fuels and one-third from nuclear fuel; Ontario Hydro produces approximately 94 per cent of the former and all of the latter. Some electricity is generated in small diesel and gas-turbine stations using oil as fuel, but this is not shown on the chart.

The large quantities of heat rejected by the thermal power stations – nearly enough to heat all of the residences in Ontario – is apparent from the chart. The amount of heat rejected in this way has frequently given rise to public criticism of the utilities for not making use of it. The fact is that when the existing thermal power stations were designed we were not as concerned as we are now about the possibility of an energy crisis; the objective of the utilities was to provide a reliable supply of electricity as cheaply as possible. For thermodynamic reasons, this required that the heat should be rejected at a temperature close to that of the atmosphere or of readily available cooling water – a temperature too low for it to be of use elsewhere. If existing stations were to be modified so as to reject heat at a more useful temperature, their electrical output would fall and additional power stations would be required. Furthermore, since the stations were not sited with a view to providing useful heat, the cost of transmitting heat to cities and of distributing it within the cities would be great, both in terms of money and in terms of the dislocation it would cause in cities and power stations alike. However, when new power stations are being planned, the possibility of using the rejected heat should be considered carefully.

Tables 1 and 2 summarize the distribution of energy between the

Table 1. Distribution of Energy between Final Users (percentages)

	Industrial	Transport	Residential	Commercial	Total
Coal	11	—	—	—	11
Oil and gas	21	26	16	12	75
Electricity	6	—	4	4	14
Total	38	26	20	16	100

Table 2. Distribution of Primary Energy Sources between Final Users (percentages)

	Industrial	Transport	Residential	Commercial	Total
Coal	13	—	2	3	18
Oil and gas	19	22	15	10	66
Hydro electricity	3	—	2	2	7
Uranium	3	—	2	2	7
Total	38	22	21	17	98*

*The remaining 2 per cent is used internally by the electricity supply industry.

consumer classes. The first table includes the electricity delivered to, or generated by, the final user. In Table 2, the electricity supply is broken down into its input components – hydro electricity, coal, and uranium – and also to show the division of these components between the final users.

Industrial Use of Energy

Industry is by a substantial margin the largest user of energy, in general, and of electricity, in particular. Except for a few highly energy-intensive industries, energy has formed a small part of manufacturing costs and so there have been few detailed studies of the use of energy by industry. Details of the energy flows in individual firms and industrial sectors are, with a few exceptions, not known, but some general features are understood and I will concentrate on these, emphasizing techniques for improving energy utilization that are of sufficiently widespread applicability to be of public interest.

We are all aware, through our experience of household budgeting, of the importance of simple measures such as adequate thermal insulation and good housekeeping – for example, remembering to turn off the hot-water taps and to have the furnace serviced regularly. Such measures are equally important in industry, but frequently they are not applied. Direct incentives to good housekeeping are stronger in households than in industry, where strict rules are necessary, supported by automatic controls

and energy-conserving devices (hot taps that cannot be left running, for example).

In industry there is scope for a number of measures that are not open to the private citizen. Virtually all of the fuels purchased by industry are used for space heating (that is, to provide comfortable working conditions) or for process heating (that is, to carry out some production process). The temperature at which process heat is supplied is often crucial and it may determine the best form of energy or fuel for a process. For example, where extremely high temperatures are required – for example, for melting or heat-treating metal – direct-firing or electric-arc or electric-induction heating are usually used. Direct-firing, in this context, implies placing the material to be treated either directly into a furnace or in the hot gases from it, and, if this method is employed, it is often necessary to use a "clean" fuel such as natural gas or a highly refined petroleum product, so as to avoid contaminating the process.

Except for the metals industry and some chemical plants, heat is generally required at much lower temperatures and is usually produced in a central furnace and transported around the factory, steam being the most common transport fluid. The choice of fuel is then determined by economic and environmental considerations. In large factories, particularly in chemical plants where the demands for heat and electricity are steady, steam is often produced at a higher temperature and pressure than the process requires and then expanded through a turbo-generator to produce electricity. The steam leaves the turbine in a condition suitable for the industrial process. This can result in very efficient use of energy, but the technique has not penetrated widely into industry, especially not into medium-sized firms, because small turbines, high-pressure boilers, and the associated equipment are relatively expensive.

It is also possible, using diesel or gas engines, to produce approximately one unit of electricity for each unit of heat recovered from the engine exhaust and the cooling water, and to recover the heat at temperatures that match many industrial heat requirements. In most factories, since the electrical energy used is less than one-third of their low-temperature heat requirements, equipment of this kind would generate a surplus of electricity. There is little incentive for an industrial firm to generate electricity in this way because the laws, practices, and traditions governing the operations of large utility companies make it difficult to sell

such a surplus at a worthwhile price. The extra cost to an industry of providing a stand-by supply of electricity in case of failure acts as an additional deterrent. Yet this technology, which is immediately available, could save large amounts of energy, and would cost the community little or nothing extra in terms of other resources, compared with the cost of constructing large oil- or gas-fired power stations. As a way of using waste heat, it would be more effective than piping it over long distances from large central stations. Also, since much of the electricity generated would be used locally, significant savings in transmission-line construction would be possible. The utility companies would take on the additional role of distributing locally generated electricity. A well-designed tariff would be necessary, supported by a method of transferring to the industrial generators some of the capital costs saved on the construction of large power stations. The legal framework within which electricity is generated and supplied would also need to be closely scrutinized.

An alternative system for the supplying of heat and electricity is compared with the conventional system in Figure 2, showing that 1.21 units of fuel could be saved for every unit of useful low-temperature heat supplied to industry. Ontario industry's total annual requirement of low-temperature heat probably exceeds 250×10^{12} BTU; the adoption of this system by industry could produce approximately 275×10^{12} BTU (i.e., 88,000 million kW.h, or about 90 per cent of the present electricity consumption of the province). The saving in primary fuel input would be 302×10^{12} BTU, or about 12 per cent of the total primary fuel consumption. A change of this magnitude might, of course, be undesirable since it would imply a switch from coal and uranium to gas and oil, but the alternative is certainly more attractive than the burning of oil or gas in central power stations. Research into new ways of burning coal – in the so-called fluid-bed boiler – holds the promise of cleaner and more efficient operation of small industrial boilers. This could encourage a wider use of coal by industry, and it could be associated with local generation of electricity.

Of the electricity consumed by industry, some 70-80 per cent is used to drive electric motors. Most of these are the simple induction motors used throughout industry – for example, for pumping, blowing, mixing, and stirring in the chemical industry and for powering lathes, grinders, and millers in the mechanical engineering industry. Although the basic efficiency of the electric motor is high, its characteristics are unsuited for most applications

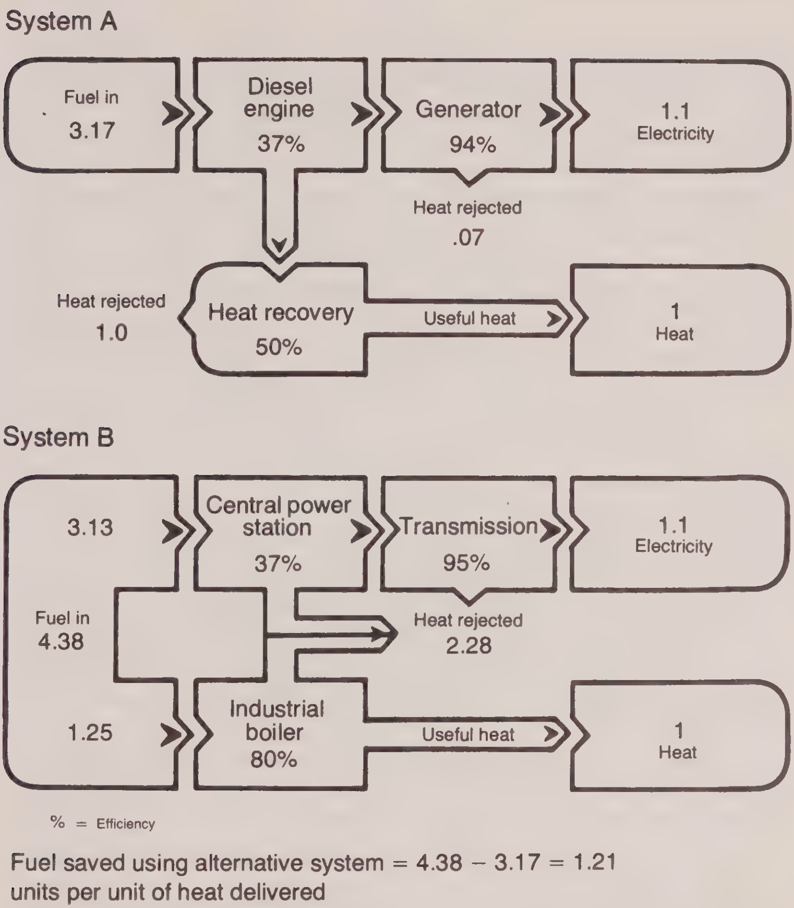


Figure 2. Comparison of two systems for supplying heat and electricity: conventional (System B) and alternative (System A).

and have to be modified by means of gears and clutches or, in the case of pumps and fans, by manipulating throttle-valves. In practice, nearly all of these devices spend most of their working lives operating well below capacity and so are relatively inefficient.

With a lathe, for example, the drive must be designed for the highest speed and power likely to be required, but most of the operating time is spent at much lower speeds and powers. Moreover, the design is usually conservative, to minimize the risk of failure, as this is costly to the user. Similarly, industrial pumps and fans are usually overdesigned and operated at a fixed speed,

and any requirement for a variable flow is met by manipulating a flow-valve – a cheap and reliable, but wasteful, procedure. A recent study in the United Kingdom concluded that the efficiency of electrically produced motive power over the working day probably varies from less than 50 per cent in the chemical industry to less than 30 per cent in the general engineering industry. The development of an efficient, cheap, variable-speed, controllable drive would make an important contribution to energy-saving. Efficient, variable-speed electric drives are still expensive, but there is a growing interest in the use of oil-hydraulic systems to distribute energy within factories, because of their high efficiency, modest cost, and flexibility. If the over-all efficiency of industrial electrical drives was raised from its present level to, say, 80 per cent, a 25-30 per cent reduction in the demand for industrial electricity could result.

The 10-20 per cent of electricity that is not used for motive power is used principally for lighting, electric welding, and specialized electric heating. Steady progress has been made in illumination technology – in improving the effectiveness of lighting units and in developing and promulgating adequate lighting standards. It is fairly easy to demonstrate the advantages of new equipment in this field, and industry has, in general, responded well. Electric welding and the specialized use of electric heating, where its cleanness, flexibility, and controllability are admirably matched to the needs of precision production processes, are good illustrations of the wise use of electricity. Well-designed electric induction, infra-red, or microwave heaters can achieve higher over-all energy efficiencies than direct-firing by gas or oil.

Residential Use of Energy

Throughout this century there has been a steady increase in the quantity of energy we use each year in our homes. The demand for higher standards of comfort in winter and summer, and our desire to be able to wear light clothing in any part of the home throughout the year, have led to a continuous increase in the consumption of fossil fuels for central heating. The development of a reliable electricity supply with its unique advantages over gas and oil for lighting led to a demand for electricity to be distributed to residences, a demand that was soon followed by its use for the

production of mechanical power in washing machines, mixers, dishwashers, fans, and pumps. Later, radio, television, and air-conditioning added to the demand. As a result, the domestic use of electricity has grown more rapidly than the over-all domestic use of energy.

An approximate breakdown of residential energy consumption for conditions typical of North America is shown in Figure 3. It is clear from this that nearly 90 per cent of the energy we consume in our residences is used for central heating and to produce hot water, that 95 per cent of this heat is supplied directly by oil and gas, and that this use accounts for about 94 per cent of the residential consumption of these two fuels. The pattern for Ontario is broadly similar.

Natural gas is an excellent fuel for domestic central heating, especially in cities where pollution problems are critical and where distribution networks exist, and its use for this purpose has been generally encouraged, to such an extent that many countries impose restrictions on its use by industry and electricity utilities so as to conserve it for residential use.

In Ontario, the use of electricity for space heating grew rapidly during the decade or so preceding the recent energy crisis: the average annual growth rate between 1961 and 1971 was 15.5 per cent, whereas the growth rate for water heating was negligible. Electrical heating has many advantages for residential use. It is clean, requires little maintenance, and can respond quickly to the users' needs and to changing weather conditions. The installation cost is also relatively low and this makes it attractive at first sight, particularly to less affluent home-buyers.

Generally speaking, electricity is economical for space-heating in homes only where there is abundant hydro power, as has been the case until recently in Ontario. It also makes good use of national resources, because it helps to build up a load for the hydro stations and to conserve other energy resources. However, in Ontario as in most highly developed areas of the world, the demand for electricity has far outstripped the resources of cheap hydro electricity, and these have traditionally been supported by thermal power stations using fossil or nuclear fuels. Electric space heating, then, becomes less and less attractive to the user and to the nation. A thermal power station using gas or oil requires roughly twice as much fuel to produce electricity for space heating as does a directly fired domestic gas or oil boiler.

Of course, there are fuels such as coal and uranium that cannot

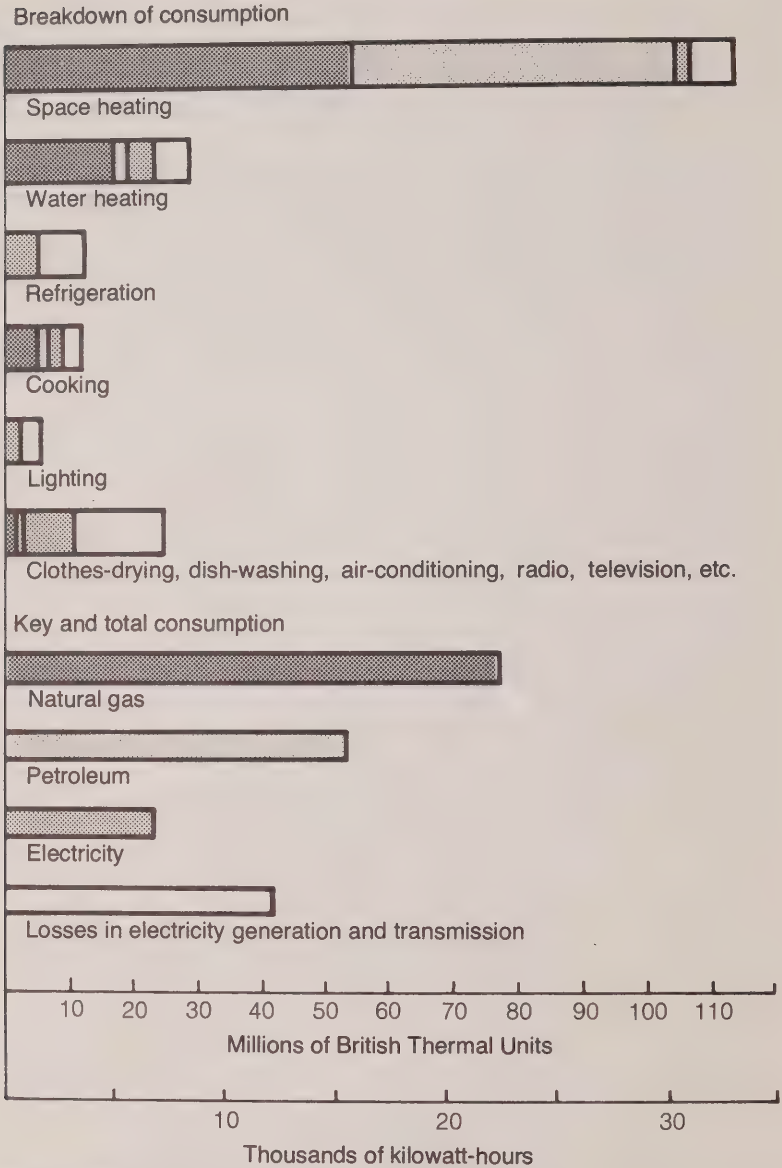


Figure 3. Typical annual residential energy consumption in North America – 1968. (Source: Stanford Research Institute report PB-212 776, January 1972)

at present be used in an acceptable way in residential boilers. Until technologies are developed for using coal cleanly and economically at the domestic level, its consumption in large power stations will continue to be the best way of using it. The use of nuclear electricity for space heating raises a different set of problems, which we must now consider.

Residential space heating and water heating require so much of our energy resources that a great deal of thought is being given to alternative ways of filling these needs – ways we might have to adopt if fossil-fuel resources become too expensive. It can be argued that we will have to rely eventually for our energy supplies almost entirely on nuclear fuels, that this must lead to a major growth in electric heating, and that people should therefore be encouraged to prepare for this situation now by installing electric heating in new houses. It would certainly be technically possible to proceed in this way, but it would create some serious problems. The residential consumption of energy for heat is such a large part of the total residential use of energy that a substantial switch to nuclear electricity for heating would require a nuclear program several times as large as the one envisaged at present, and an associated increase in the transmission-line capacity. This would be an inefficient way of using nuclear fuel, and the over-all cost in economic and environmental terms could be severe.

However, the electricity requirements for house heating can be reduced considerably by the use of heat pumps. The action of a heat pump may be compared with that of a refrigerator. Essentially, it is a device for pumping heat energy out of an insulated box and discharging it into a room that is at a higher temperature. Because heat will not flow spontaneously from a lower temperature to a higher temperature, work, supplied in this case by electricity, is required to make the heat flow. So the refrigerator is a kind of heat pump. The same principle can be used to pump heat from the atmosphere, from the ground, or from a river or sea into a building that is at a higher temperature. The amount of heat transferred into the building can be three or four times the electrical work supplied; in other words, the electricity consumption can be reduced to between one-third and one-quarter of that required by conventional electric heating. Although heat-pump installations are likely to remain considerably more expensive than conventional electric heating, the extra investment by the community as a whole might well be fully offset by the saving in nuclear power plant, transmission, and distribution costs.

Another way of using nuclear power stations for residential heat is to circulate through district heating networks the heat that is normally wasted by these stations, and to use it to heat residential and other premises. The nuclear power stations would have to be designed so that they could supply heat at a temperature high enough to match the district heating requirements. This would lead to a less efficient generation of electricity, but the loss would be more than offset by the fact that much of the heat normally wasted would be used. Many district heating schemes exist in the world, especially in the U.S.S.R. and Scandinavia, but they use small, local power stations burning fossil fuels. The use of large nuclear stations for district heating poses new problems. Unless the stations could be sited near large towns that could use the heat, long and costly heat-pipelines would be required. Moreover, although a single nuclear plant could provide district heating for a large town, the conversion of such a town to district heating would be a long and expensive process and one that would seriously disrupt the life of the citizens.

There is yet another way of using nuclear fuel for heating, which is to use reactors to produce an artificial fuel that can be substituted for oil or natural gas. It is certainly possible to use nuclear electricity to electrolyse water and so produce hydrogen. Hydrogen can be burned directly as a gas or it can be used to "pep up" the limited supplies of fossil fuels (coal, for instance) to produce substitute natural gas or liquid fuels such as methanol. But since the start of this complicated process is electricity – which, as we know, is produced in nuclear power stations with an efficiency of less than 40 per cent – and since the subsequent transformation of electricity into hydrogen and other fuels entails further losses, we may well ask why there can possibly be any interest in this method.

There are two reasons why the method could be useful. First, if we could produce the right kinds of artificial fuel, we would have a highly versatile energy source. "Artificial natural gas" may be less costly to distribute to residences than electricity. It might be possible to use existing natural gas networks and to retain most of our gas appliances, with minor modifications. The fuel could be shipped in tanks to remote townships and dwellings and – very important – might provide fuel for our vehicles after petroleum supplies are exhausted and thus prolong the usefulness of our road transport system. Secondly, since the fuels can be stored easily, they could be produced at times when the normal demand for

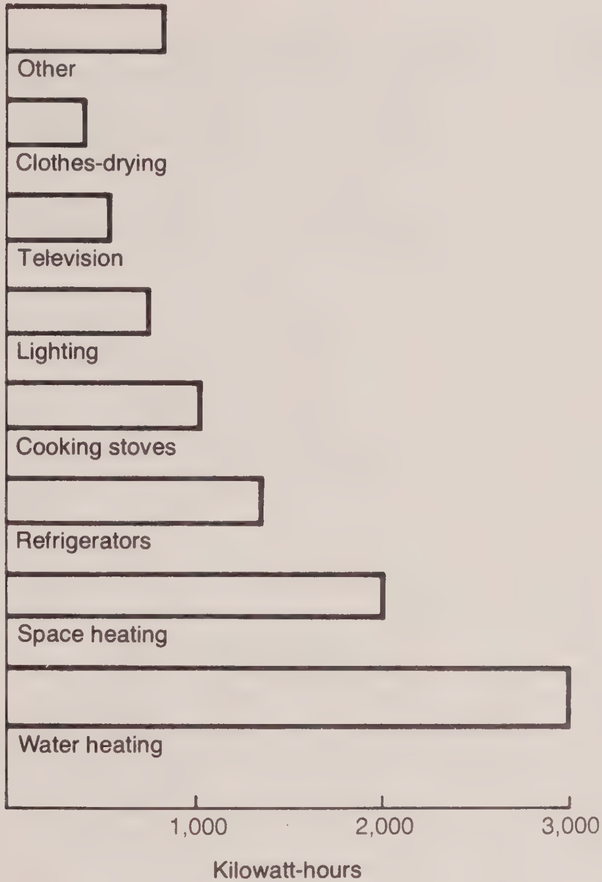


Figure 4. Breakdown of average residential electricity consumption in Ontario in 1974. (Source: Ontario Hydro)

electricity from the power stations is low, resulting in a more effective use of expensive nuclear plants. There is also a possibility that the fuels could be produced by direct chemical conversion in a reactor, without the use of electricity; this could be a more efficient process.

Yet another approach to domestic heating is possible, using thermal storage. With this technique we would absorb energy when it is readily available into a storage medium, and withdraw it as required. Thermal storage electric heaters are very common in homes in the U.K. During the night, when electricity is cheaper to

supply, it is fed into a storage heater to heat firebricks. During the day the bricks are cooled by fans that distribute the heat through the house. Compared with conventional electric heating, this means a saving in fuel, because during the night, when the electricity demand is smaller, only the most efficient generators are operating. There is also a saving of resources by the reduction of the peak electricity demand and hence of the number of power stations required. It seems certain that the effective use of solar energy for domestic heating will require extensive use of thermal storage techniques.

Heating accounts for about one-half of Ontario's electricity consumption and almost all of its oil and gas consumption. Figure 4 shows the breakdown of residential electricity consumption in 1974. After space heating and water heating, refrigerators and cooking stoves are the most significant consumers, followed by lighting. The rate of growth of energy consumption for those purposes is relatively slow, because the market penetration is already nearly 100 per cent for refrigerators and lighting, and 80 per cent for electric cooking ranges. In these conditions, a growth in consumption can only result from people buying more powerful or more sophisticated equipment. For example, the number of refrigerators increased very little between 1961 and 1971, but the energy consumed by them increased two and one-half times despite the fact that insulation standards probably improved; this was due principally to the increasing use of automatic defrosting and frost-free devices. A similar effect can be observed during the transition to colour television from black-and-white television.

Energy and Transportation

Approximately one-quarter of Canada's energy consumption is for transportation and about 99 per cent of this is in internal combustion engines, more than half of it in automobiles. Internal combustion engines, operating on petroleum products (diesel oil or gasoline), play a very significant role in the depleting of our stock of fossil fuels. By their very nature, they must be relatively small and mobile, so that some of our future energy-supply options, such as nuclear and solar energy, are not directly applicable to them. Transportation, therefore, poses a major challenge for our energy planners.

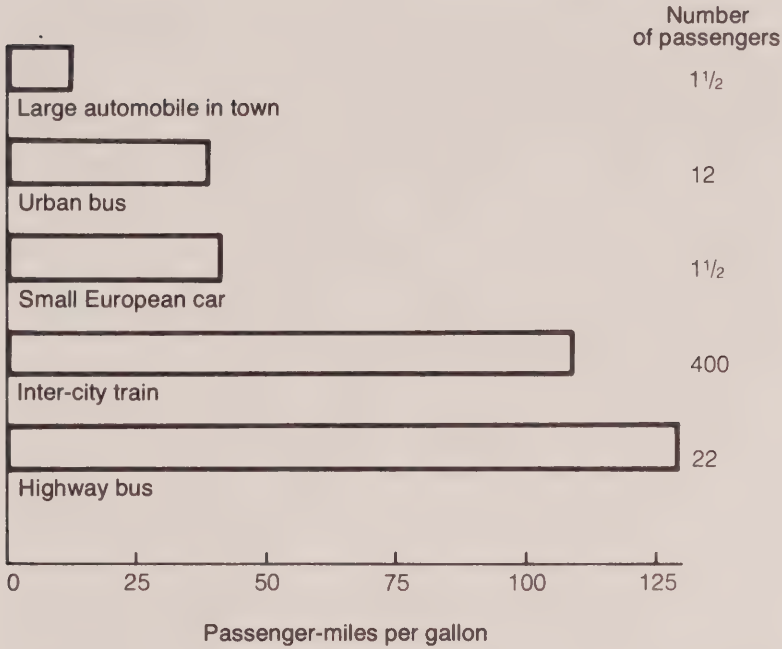


Figure 5. Comparison of the efficiency of various forms of surface transport.

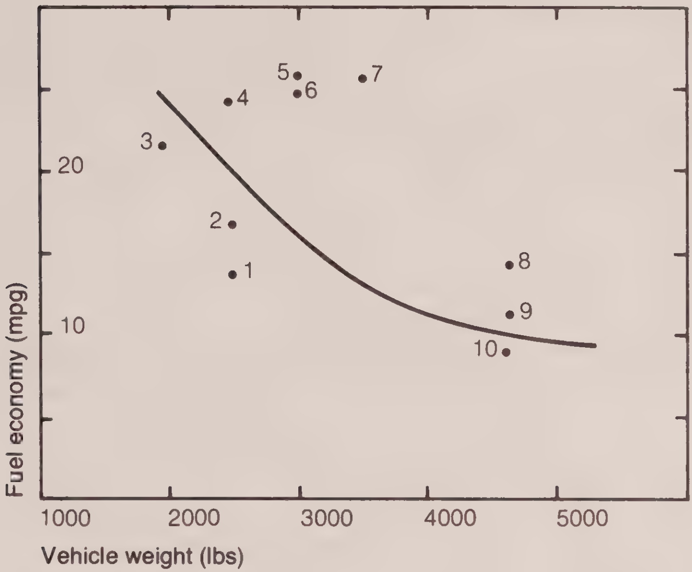
The size and scattered population of North America, and the relatively low taxes on petroleum fuels, have encouraged the widespread use of automobiles that are large and thirsty by the standards of Europe or Japan. The spark-ignition gasoline engine is almost universally used for road vehicles in North America because of its cheapness, smoothness, and ease of starting. Its efficiency (in the use of energy) never exceeds 25 per cent and is much lower than this when averaged over a typical journey. Auxiliaries such as automatic transmissions, power steering, and anti-pollution devices further reduce the efficiency, so that (as may be seen from Figure 5) the automobile competes most unfavourably with other forms of surface transport. Private automobiles have become a part of our way of life, and many facets of our infrastructure – roads and residential habits, for example – are based on it. It would take a great deal of persuasion and money to effect any major change in the foreseeable future away from an automobile-owning society towards one in which public or communal transport was the major mode.

Much can be done to reduce the drain of the automobile on energy resources. The use of smaller and more efficient vehicles is spreading, and more efficient gasoline engines are beginning to appear. The diesel engine, well known for its reliability and much more efficient than the gasoline engine, is already common for European taxicabs, and is fitted to some private automobiles in Europe. Until recently there has been no strong incentive to develop special diesel engines for automobiles and a number of disadvantages remain to be overcome – in particular, poor starting in cold climates, poor acceleration, engine noise, and exhaust smell. The fuel consumption of some of the alternative types of automobile engines is shown in Figure 6.

If in the future we need to move away from liquid fossil fuels for road transport, two major options appear to be available, although as yet neither has been shown to be acceptable economically or in terms of convenience. We could, in principle, use electric automobiles powered either by storage batteries or by fuel cells that would be recharged from the electricity network, thus making use of nuclear- or coal-fuelled power stations. Major improvements have been made in storage batteries in the last decade, but there is still no certainty that a battery can be produced that is acceptably cheap, small, efficient, and able to give an automobile the kind of performance we have become accustomed to. If a satisfactory battery is eventually produced, the problem of recharging remains. This would be done mainly during periods when the electricity demand for other purposes is low, but the extra demand on the electricity supply would still be very large and could require an expansion of roughly 50 per cent in our generating system. The distribution network would also need substantial strengthening, to provide enough vehicle recharging points.

The second option is to produce an artificial fuel. We have already discussed this in connection with the use of energy in residences. If the fuel was produced electrolytically, the primary energy input to the power stations could well be larger than with the storage battery option, but since fuel can be stored for long periods, whereas it is possible to consider only day-to-day storage of energy with batteries, the load on power stations could be smoothed out over the year, leading to their more effective use and to a reduction in the number of stations needed.

Taking a broad view, therefore, the transportation sector is the most difficult one from the point of view of fuel substitution, and it seems likely that petroleum and diesel oil will have to be depended



Type of engine and vehicle:

1. Wankel — Mazda
2. Texaco stratified charge — Jeep
3. Honda stratified charge — Honda
4. Ford (Procol) stratified charge — Jeep
5. Diesel — Peugeot
6. Diesel — Opel
7. Diesel — Mercedes 220-D
8. Stirling engine
9. Rankine
10. Gas turbine

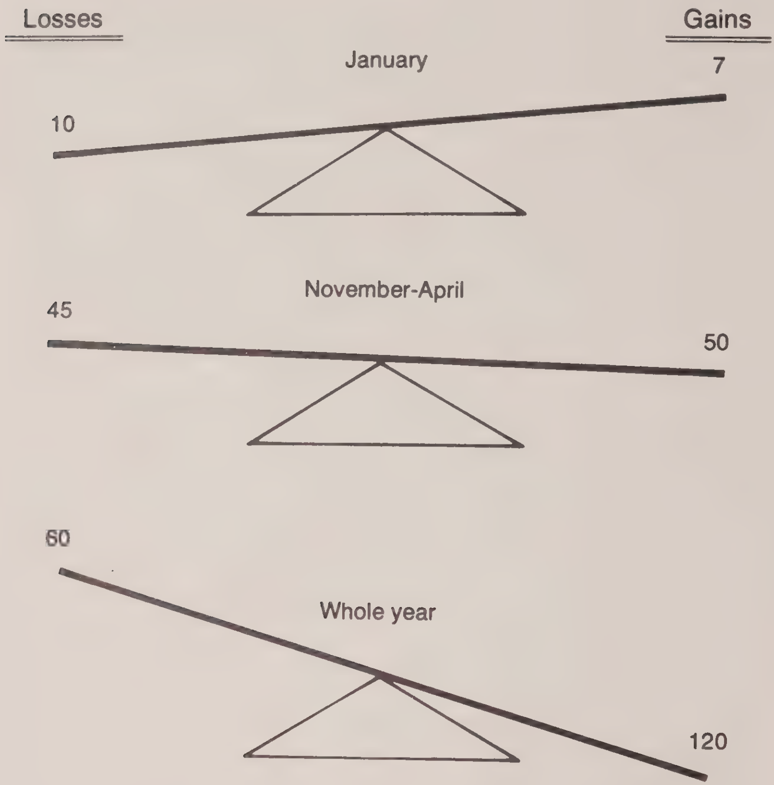
Predicted performance

Figure 6. Comparison of fuel consumptions of various automobile engines. (Source: *Automotive Engineering,* Vol. 81, No. 7, 1973)

on for the foreseeable future. This might require us to make more rapid changes in other sectors so as to conserve our petroleum for transportation, at the same time taking what steps we can to get better mileage per gallon from our road vehicles.

Energy in the Commercial Sector

The commercial sector includes, apart from strictly commercial



Units are thousands of BTU/sq. ft.

Figure 7. Heat losses and gains in a typical commercial building in Toronto. (Source: "The Case for Thermal Storage" by Bob Tamblyn, Engineering Interface, Toronto, July 1975)

concerns, the use of energy for street lighting and many other non-commercial services. In this sector, energy is used almost entirely to provide heat and light. Over the last 25 or 30 years, the trend in office-block construction has been towards the use of large areas of glass. These gain and lose heat quickly as climatic conditions change and require more sophisticated and energy-thirsty heating and cooling systems than older buildings. The trend has been encouraged by the availability of cheap energy and by the fact that priority is given to reducing the initial cost of buildings, often at the expense of the subsequent running costs.

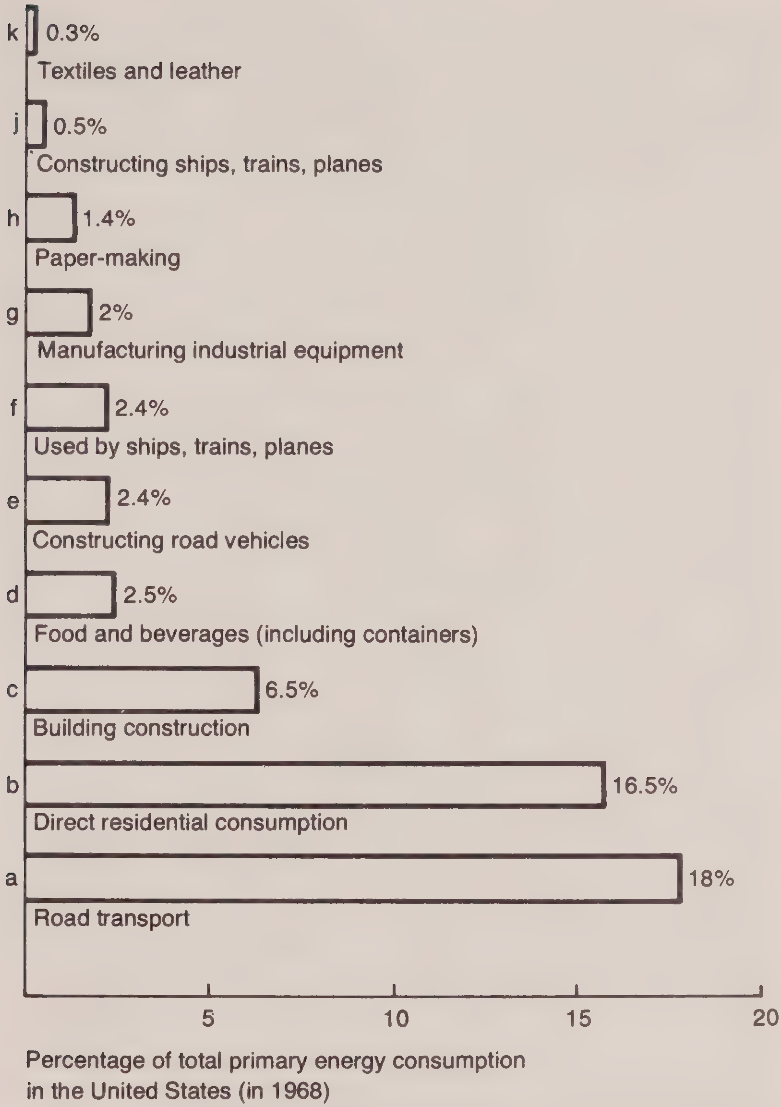


Figure 8. Comparison of some important areas of energy consumption in the United States. (Source: "Energy and Well-being" by A. B. Makhijani and A. J. Lichtenberg in *Environment*, Vol. 14, 1972)

An exciting new prospect is opening up as a result of co-ordinated efforts bv architects and engineers. They have found that, in a properly designed commercial building, the heat of the sun together with the heat generated by the occupants, the lighting, and the equipment they use, averaged over the year, can exceed what is required to provide comfort levels of heating in the building. Figure 7 illustrates the balance between the heat gains mentioned above and the heat losses to the surroundings, for the Toronto area. It is surprising that, even for most periods of the Canadian winter, a building can gain as much heat from these sources as it loses as a result of its structure and its ventilation system.

By providing for storage of the excess heat so that it can be used later, when needed, the annual energy input to a building can be greatly reduced, though in practice it cannot be eliminated entirely. The energy store might be a large insulated tank of water in the basement of the building. In general, it may be said that relatively little attention has been given until recently to energy costs in large buildings. However, the situation is changing rapidly and we may expect to find the rate of growth of consumption in this sector falling off as new ways of constructing buildings and new heating and cooling techniques find acceptance.

It is perhaps interesting to learn how much energy goes into some of the things we buy and do and into some of the activities we see around us. A few examples have been selected and are tabulated in Figure 8. All the items listed represent about 52 per cent of the total energy consumption. The first two are two of the four major sectors; the others are chosen from the industrial and commercial sectors. If we compare items (a) and (e) we see that the average road vehicle consumes in six weeks an amount of energy equal to what was used to make it, including the making of the steel and other materials of which it is constructed.

The Way Ahead

Although a good deal of publicity has been given to the question of supplies of primary energy on a national and international basis, we should not forget that what we, as final users, actually seek is to satisfy our requirements for heating, cooling, lighting, movement,

and so on. For this to happen, there must be two basic inputs – primary energy, and the resources necessary to transform the primary energy into the required final form. Although the second of these inputs is usually measured in monetary terms – e.g., in dollars per kilowatt capacity for a power station – this is only a way of measuring other resources (materials, labour, and environmental control) that go into the energy-transforming equipment. The two commodities, primary energy and capital, can to a great extent be traded off against each other – for example, a cheaper fuel (uranium, for instance) can be used by constructing a more expensive power plant. In the extreme case, if we are prepared to deploy the necessary resources to construct large solar power stations, the primary energy input becomes virtually free and unlimited. At present this extreme is not viable economically.

It seems certain that as we are forced to move from our diminishing stocks of petroleum and natural gas (which are very flexible and have been cheap in the past) to fission and perhaps fusion fuels, and eventually to renewable resources such as solar energy, the emphasis will move away from the input of primary energy and towards the input of resources that are needed to transform it. As this happens, the total quantity of the resources that must be devoted to energy will be determined less and less by the quantity of energy used and more and more by the maximum rate of use, i.e., by the maximum power demand on the system at any given time. There will therefore be an increasing dividend to the community from a minimizing of peak power demands. There are two important ways of doing this: by using more efficient equipment, and by the storing of energy.

The most effective point in the system at which to introduce a device for improving efficiency is at the final-user end, since a reduction in the demand for power will be reflected right back down the line in reduced capital costs. Also, there is nearly always more scope for improvement at the final-user end. In the case of energy-storage devices, which can make better use of invested capital by storing off-peak energy and releasing it later, it is not always obvious where the storage capacity should be placed.

I have mentioned a number of optional energy systems for the future, some now technically possible and others expected to become so. I have also mentioned a few techniques for improving our transformation efficiencies and for storing energy. These are essentially feasible today and will become more important in the future. In fact, our escape from the impending fuel-supply

bottleneck may depend on how effectively we make use of them. In setting out to achieve this, we must be sure that we do not constrain ourselves by habits of thought, or by institutions and institutional behaviour, or by legal restrictions that originated in an age when we were not alive to the need for long-range, comprehensive energy planning.

Environmental and Health Issues of Power Generation

Donald N. Dewees

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For the last few decades, the consumption of electrical power in Ontario and in all of North America has been growing at the rate of about 7 per cent each year, which means a doubling of consumption every decade. The environmental consequences of this growth in electricity generation, and of economic growth in general, have caused concern in recent years. In fact, every known method of generating electricity creates side effects that may be damaging or undesirable for people or for the environment.

Ontario's traditional hydraulic method of generation can necessitate the flooding of vast areas, greatly changing the ecology of river basins. The burning of fossil fuels (coal, oil, natural gas) to produce steam can cause the emission from smokestacks of materials that are potentially harmful to plants, animals, and man. In addition, large quantities of warm water are discharged into bodies of water near the stations, and this can upset fish populations. The use of nuclear energy to produce steam releases large quantities of waste heat to the water, produces dangerous radioactive wastes that must be disposed of, and raises the possibility, however remote, of an accident that could release substantial amounts of radiation.

My purpose here is to summarize our current knowledge about the environmental pollutants that are released by the generation of electricity in Ontario. Each pollutant and its origin in the electricity generation process will be described; the effects of the pollutant will be recounted briefly; and I will indicate the current state of the art of reducing the emissions of it. It must be remembered that most of these pollutants are also discharged by other sources.

Donald N. Dewees

Air Pollution from Fossil Fuels

In 1975, 31 per cent of the electricity consumed in Ontario was produced by burning fossil fuels to produce steam to power generators. The fossil fuels can release three kinds of air pollutant: particulates, sulphur dioxide, and oxides of nitrogen. In addition, all fossil-fuelled generating stations, as well as nuclear-powered ones, discharge large volumes of waste heat in the form of warm water.

Particulates are small particles of ash, unburned fuel, and other substances that are discharged through the smokestack of a fossil-fuelled station. The size of the particles ranges from matter similar to fine sand to particles too small to be seen by the naked eye. When you see black or grey smoke coming from a factory or incinerator chimney, it is probably caused by particulates similar to those produced in the generation of electricity. Because Ontario Hydro has installed pollution control devices ("electrostatic precipitators") to reduce particulate emissions, it is seldom possible to identify particulate emissions from electricity generating stations in Ontario by the smoke.

The composition of particulate emissions depends upon what was in the fuel, and the conditions under which it was burned. Studies of the particulate emissions from a number of coal-combustion units have revealed many elements including carbon, iron, calcium, aluminum, and sulphur. In some cases, these elements represent incombustible matter that was mixed with the fuel and blown out when the fuel burned. In other cases, the elements were in the fuel and were in fact burned during the combustion process, but the result of combustion is a solid rather than a gas.

The primary source of particulates in the generation of electricity is the combustion of coal. Whatever the source of the coal, it always contains some materials other than the carbon and hydrogen that provide its primary fuel value. The incombustible portion is called ash. The coal burned by Ontario Hydro contains about 10 per cent ash by weight. Before being burned, the coal is pulverized to make it easier to distribute and burn. In the combustion process, the larger pieces of ash remain in the furnace bed and are discarded. Some of the ash will be in very small pieces, however, and it is this fine ash that is caught up in the swirl of hot gases through the boiler and carried to the smokestack as "fly ash".

A lesser source of particulate emissions is the combustion in power plants of residual oil, which is the residue after crude oil has been refined to produce gasoline, heating oil, and other products. The oil itself may contain a small amount of ash, which will be discharged as particulates through the smokestack. In addition, if an oil-burner is not properly adjusted, some of the oil may not burn completely, leaving small particles of unburned carbon or hydrocarbon that will be discharged as particulates. However, the quantity of particulates from oil-burners is much smaller than the quantity from coal-burners.

The chief reason for public concern about particulate emissions is the effect of this pollution on health. Statistical studies have related high levels of particulate pollution in some cities to increases in the incidence of some diseases, and even occasionally to increases in the mortality rate.[16] Particulates have their greatest effects on the respiratory system. When a person or animal inhales air that contains particulates, the smaller particles are drawn into the lungs, where they are deposited on the membranes. It is believed that the particles that are retained in the respiratory system are able to irritate the membranes, and that they produce or aggravate certain respiratory symptoms and problems. In particular, high levels of particulate pollution seem to be associated with increased incidence of bronchitis and possibly with other respiratory diseases, lung cancer, and cardiovascular disease.[7]

It is not possible to identify a specific level of particulate pollution as safe, and other levels as unsafe. Existing studies only show that, when high levels of particulate pollution are reached, some increase in disease is likely.

There are other important effects of particulate pollution. If the particulate density is high, the effect on the atmosphere can be to reduce visibility and replace a clear sky with a murky one. When larger particles are involved, residents near a source may find that particles are deposited on windows and on outdoor furniture. There may be a significant increase in the frequency with which clothes and drapes have to be cleaned or laundered.

Fortunately, effective means are available for controlling the emission of particulates. Electrostatic precipitators are available that can remove up to 99.5 per cent of them from smokestack gases. Thus, if the best available technology is applied, only 0.5 per cent of the particulate matter that leaves the boiler of a generating station will reach the atmosphere. While across North America the average generating station has particulate controls that are about 80

per cent effective, the coal-fired generators in Ontario are controlled to at least 99 per cent.[11] Since the cost of highly efficient electrostatic precipitators is only about one per cent of the total cost of generating electricity, these high levels of control are achieved without a serious penalty to electricity consumers.

While electrostatic precipitators can solve much of the problem of particulate air pollution, they create another problem: how to dispose of the fly ash that is captured from the flue gas. The more than 600,000 tons of fly ash collected annually in Ontario has a volume of more than 3 million cubic feet. It would fill a football field to a depth of almost 50 feet. If fly ash is piled outdoors, it may be blown about by the wind, re-creating the air pollution problem that was supposed to have been solved. Transporting it to landfill disposal sites is costly, and rainwater percolating through such sites may dissolve harmful chemicals and carry them into underground or surface water flows. Thus, disposal of the fly ash is in itself an environmental problem.

Sulphur Oxides

Most types of coal contain some sulphur, ranging from less than one per cent to 6 per cent or more by weight of the coal. The coal used by Ontario Hydro averages less than 2.5 per cent. This sulphur is usually in small quantities scattered widely through the coal, so it is not possible to separate it mechanically. Many types of crude oil also contain some sulphur, much of which is still present in residual oil, but more concentrated. When either coal or residual oil that contains a significant amount of sulphur is burned, the sulphur also burns, forming sulphur dioxide or sulphur trioxide gas, which is carried to the atmosphere with the other stack gases. In addition, some other compounds called sulphates, involving sulphur, oxygen, and other elements, may be formed.

Sulphur dioxide is a non-flammable, colourless gas. When concentrations of it reach one part per million, it can be detected by the average person as a taste in the air. At higher concentrations, it is noticed as a very unpleasant odour.

Sulphur trioxide may be formed in the combustion process, or it may result from the reaction in the atmosphere between sulphur dioxide and oxygen. Sulphur trioxide will react with water vapour in the atmosphere to form sulphuric acid. While the acid

concentrations that are thus formed are quite weak, it has been possible in northern Europe and Scandinavia to measure significant acidity in the rainfall, which is attributed primarily to the emission of sulphur dioxide from coal combustion in England and on the Continent.

A primary cause for concern about oxides of sulphur is that both sulphur dioxide and the sulphuric acid that is produced from sulphur trioxide in the atmosphere are irritating to the human respiratory system. Experiments have shown that exposure of humans and animals to high levels of sulphur dioxide, even for short periods, can cause significant changes in the performance of the respiratory system. Studies in polluted cities have shown that the occurrence of respiratory diseases and of deaths from respiratory diseases both tend to increase when sulphur dioxide concentrations are high.[7, 17] As with particulates, the primary diseases associated with exposure to high levels of sulphur oxides are bronchitis, lung cancer, some other internal cancers, and heart disease. It has not been determined that there is a threshold level of concentration below which no harm occurs. It seems more likely that the health effects begin at a low level and increase in some proportion to the increasing concentration of, and exposure to, these oxides.

Recent medical research has indicated that sulphates may be important as a cause of some health problems that have previously been attributed to sulphur dioxide or particulates. A study of health and pollution data in several areas of the United States during 1970-71[18] indicated that increases in the occurrence of some respiratory diseases could be attributed to suspended sulphates, rather than to sulphur oxides or particulates. The concern about sulphates is recent, and little is known about how they affect health.

It has also been noted that the presence of both particulates and sulphur oxides may be more harmful to health than the sum of the effects of each individually. It appears that particulates may carry the sulphur oxides farther into the lungs than they would normally penetrate, and hold them there longer.

In addition to their effects on human health, sulphur oxides have some other harmful consequences. The sulphuric acid and sulphates that are produced from sulphur oxide emissions form small particles that can significantly reduce the visibility in the atmosphere when they are at high concentrations. Sulphur oxides in humid atmospheres will produce sulphuric acid, which is highly

corrosive and may be quite damaging to certain materials, including iron and steel, limestone, marble, roofing slate, and mortar, as well as a number of kinds of fabrics. It has been observed that bridges and other exposed steel work corrode more rapidly in atmospheres polluted with sulphur oxides than in clean areas. Buildings and statues made of limestone and marble also deteriorate more rapidly in such atmospheres.

Sulphur oxides can also be damaging to vegetation. Ornamental shrubs as well as cash crops can suffer leaf and needle destruction from substantial exposures, as well as a yellowing of the leaves or needles and reduced growth rates from lower concentrations. Plants vary enormously in their sensitivity to sulphur oxides, and in many cases it is possible to use susceptible plants as indicators of the atmospheric levels of sulphur dioxide. This also means that pollution damage can be reduced by planting shrubs or crops that are more resistant to this form of pollution.

There are three basic ways of reducing the emissions of sulphur oxides from coal- and oil-fired generating stations. The first is to remove the sulphur from the fuel before it is burned. In the case of coal, this is difficult and expensive. It has not proved economical to remove any substantial part of the sulphur from most types of coal. The second method is to purchase coal with a lower sulphur content. Because many jurisdictions in North America have set limits on the sulphur content of coal, there is currently a large premium on low-sulphur coal, compared with high-sulphur coal. While Ontario currently purchases its coal from the United States, primarily from Pennsylvania, it is possible to use coal from Alberta and Saskatchewan in Ontario generating stations. Western coal has a much lower sulphur content than the imported American coal that is being used, but its costs are increased by the freight charges. Ontario Hydro plans to begin mixing some western coal with imported coal to achieve a lower average sulphur content.

In the case of residual oil, it is technologically feasible to remove much of the sulphur in the refining process, at a cost of up to one dollar per barrel. While this would mean a substantial addition to the total cost of residual oil, and it would take several years to modify refineries so that they could de-sulphurize their residual oil, it is at least a feasible means of reducing emissions from oil-fired power plants.

The third approach to the controlling of sulphur oxide emissions is to remove the sulphur oxides from the stack gases after the fuel

has been burned. A number of processes are available for de-sulphurizing stack gases.[14] Unfortunately, operating experience with most of these devices is rather limited, so their cost and reliability cannot be established with any precision. It is clear, however, that the cost of de-sulphurizing stack gases can add substantially to the cost of the fuel – perhaps 25 or 50 per cent. Thus, the installation of current technology for stack-gas de-sulphurization could raise the price of electricity by 10 per cent or more.

Furthermore, many of the de-sulphurizing processes that are available generate a large volume of solid or liquid waste, which is difficult to dispose of. For example, the lime/limestone method in a generating station the size of Lakeview may produce up to 1,000 tons a day of a mixture of pulverized limestone and sulphur in water.[13] If discharged into a river or lake, this would cause a serious pollution problem. The alternative is to store it in large ponds where the water and solid matter can be separated, and then dispose of the solid matter in a landfill, or try to reclaim it for recycling. Landfill disposal at Lakeview could fill about an acre a year to a depth of 30 feet.

It is technologically feasible, then, to reduce the emission of sulphur oxides from stack gases. Whether one changes to low-sulphur fuels, or to the technology of stack-gas scrubbing, the cost of control will be much greater than the cost of controlling particulates. While we may hope that technological progress over the next five or 10 years will reduce the cost of stack-gas scrubbing or make it more reliable, it is difficult to predict this with any assurance.

Oxides of Nitrogen

When coal, oil, or gas is burned at very high temperatures, some of the nitrogen in the atmosphere may combine with some of the oxygen to form nitrogen oxide (NO) and nitrogen dioxide (NO_2). It appears that the temperatures reached in small furnaces, such as those used for domestic or commercial heating, are not sufficient to generate substantial quantities of oxides of nitrogen. Thus, the chief stationary source of this pollutant is large fossil-fuelled boilers, including those used for generating electricity. It should be

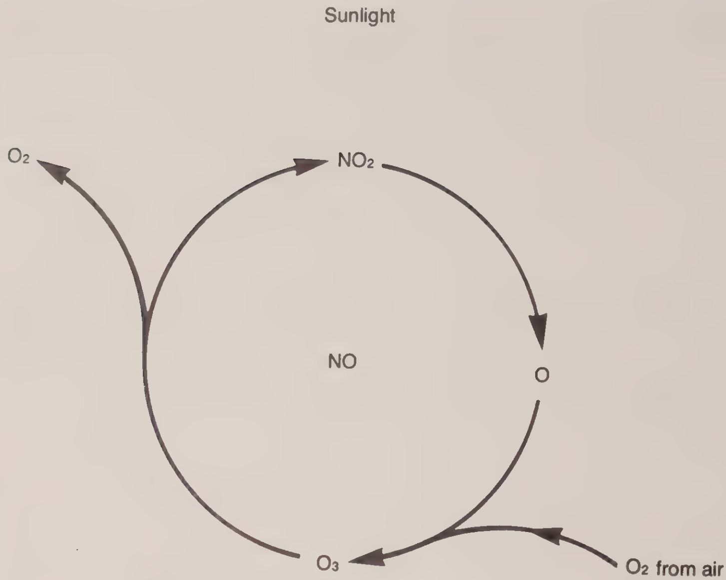


Figure 1. Atmospheric reactions of nitrogen oxides. (Source: U.S. Department of Health, Education and Welfare)

noted that automobiles and trucks also generate large volumes of oxides of nitrogen.

In a normal atmosphere, nitrogen oxide (NO) and oxygen (O_2) combine to form nitrogen dioxide (NO_2) until an equilibrium is reached. In the presence of sunlight and warm temperatures, ozone (O_3) becomes involved in the reaction, as shown in Figure 1. Here, sunlight can break NO_2 down into NO and O, which leads to the combination of O and O_2 to make O_3. Ozone can be an irritant to the eyes and the respiratory tract.

There is substantial debate over the health effects of nitrogen oxides. It seems to be agreed that nitrogen oxide (NO) is not a health hazard at the levels normally found, even in polluted atmospheres. Nitrogen dioxide, however, may be a hazard. Laboratory studies have shown that high concentrations of NO_2 can have serious health effects, primarily on the respiratory system. So far, however, public health studies have not disclosed the sort of systematic relationship between pollution concentration and disease or death that has been identified for particulates and

for sulphur dioxide. One study, in Chattanooga, Tennessee, has shown that school children exposed to high levels of NO_2 suffered poor respiratory performance and had a higher incidence of bronchitis. This study has been criticized, however, and there is not yet any firm agreement among medical scientists as to the level and seriousness of the health effects of nitrogen dioxide.[15]

There are other effects of these pollutants, however. NO_2 by itself can somewhat reduce visibility in the atmosphere, although at the concentrations that are usually found it is a relatively small factor.

Laboratory tests have shown that nitrogen oxides can damage some fabrics and dyes, but it has not been proved that these effects are significant at the levels actually encountered in the atmosphere. Laboratory tests have also shown that high concentrations of oxides of nitrogen can damage leaves and other parts of sensitive plants. It appears, however, that only particularly sensitive species are affected at the levels of nitrogen oxides that are commonly found, even in polluted Canadian cities.

One reason why there has been so much concern about oxides of nitrogen in the United States is that these oxides are one of the necessary inputs in the production of photochemical smog. In a sunny area where the atmosphere is warm, oxides of nitrogen can combine with other air pollutants to form photochemical smog. This is the famous smog that appears frequently in Los Angeles, less frequently in other cities in North America, and, on occasion, in southern Ontario. Photochemical smog reduces visibility, causes the eyes to water, and irritates the respiratory system. It has been associated with a variety of respiratory diseases. Ontario does not experience photochemical smog with the same frequency as American cities, but this condition does occur from time to time in southern Ontario, and it is therefore a matter of some concern for Ontario citizens. Thus, one of the more important reasons for controlling oxides of nitrogen is not their direct effect but their role in the formation of more serious pollutants.

Oxides of nitrogen are formed from two of the most abundant elements in the atmosphere, and it is impossible to elminate these elements from the combustion process. It has been found, however, that careful designing of the boiler in which the fossil fuel is to be burned can significantly reduce the rate at which oxides of nitrogen are formed. A uniform flame is less likely to produce oxides of nitrogen than an irregular flame.

In addition, adjustment of the burning process can reduce the

production of oxides of nitrogen. In any large boiler, the amount of air is carefully measured to ensure that there is enough oxygen to consume all of the fuel. Proper regulation of this fuel-and-air mixture can substantially reduce the rate of formation of oxides of nitrogen. It appears that up to 50 per cent of the current emissions of oxides of nitrogen could be eliminated at rather low cost by controlling the burning process, and by design modifications for new boilers. But it may be much more difficult and expensive to go beyond the 50-per-cent level of controlling this pollutant.

Health Effects of Air Pollution

So far, we have discussed the effects of air pollution on human health. But how accurate is the information? Unfortunately, the answer is: not very.

There are three ways to study the health effects of air pollution, all of which present serious problems. First, one can perform laboratory experiments on animals, for example, by exposing mice to various levels of a pollutant and recording changes in their health. This is a reasonable way to determine the diseases that are caused by certain pollutants, but because of the physical differences between mice and men it does not indicate what pollution levels would be safe for man, or by how much the incidence of a disease could be expected to be increased by a given increase in pollution levels.

A second method is to study the health records in a city that has experienced a serious, short, air-pollution episode, to determine the health effects of that increase in pollution levels. For example, the "killer smog" in London in 1952 has been widely studied. Typically, studies show that severe air-pollution episodes are accompanied by increases in respiratory diseases, and in deaths from such diseases. Unfortunately, concentrations of many pollutants increase simultaneously, so it is not possible to apportion responsibility among them. Also, non-pollution factors such as temperature and humidity, which themselves can increase disease and death rates, tend to rise in pollution episodes, and may be partly responsible for the effects.

Finally, one can compare the health records of cities with different levels of pollution. Once again, cities high in one

pollutant are often high in several, so that individual effects cannot be isolated. Furthermore, there may be other important health-related differences between cities, such as the amount of cigarette smoking, the age of the population, diet and health care, and other factors. Once again, it is difficult to observe clearly the health effect of changing levels of a given pollutant.

These problems mean that we know with some confidence the diseases that are related to certain pollutants, but have little information about changes in disease rates that result from changes in pollution levels. In addition, often we cannot tell whether there is a safe level for a pollutant, below which there is no effect. Finally, it is difficult to tell whether increases in disease are proportional to increases in pollution, or whether there is some level above which the disease rate may rise much more rapidly than the pollution level. All of these problems should be kept in mind when considering the effects of a pollutant on man.

In many jurisdictions, including Ontario, air-quality goals, or standards, have been adopted for the basic air pollutants, specifying pollution levels that should not be exceeded. Because it is often impossible to specify a level of pollution that is absolutely safe, air-quality standards are often set below the level at which significant harmful effects have been proved. The standard is based on the medical evidence available, and it may be revised if different information becomes available.

In addition, the Ontario Air Pollution Index provides a daily measure of pollution, to warn citizens and to prompt the shutting down of pollution sources if air quality falls below certain levels.

During the 1970s, increased concern about environmental problems has led to greater efforts to measure pollution emissions and the amount of pollution in the air. Records that are now being kept will make it easier to trace changes in pollution levels and to determine what causes them.

Heat Pollution

Using a fossil fuel or a nuclear fuel to generate electricity involves the same basic principles as the steam engine. Heat is produced by burning the fuel or operating the nuclear reactor, and this heat is used to turn water into steam. The steam turns a large turbine (or simply a wheel), which is connected with a rotating electrical

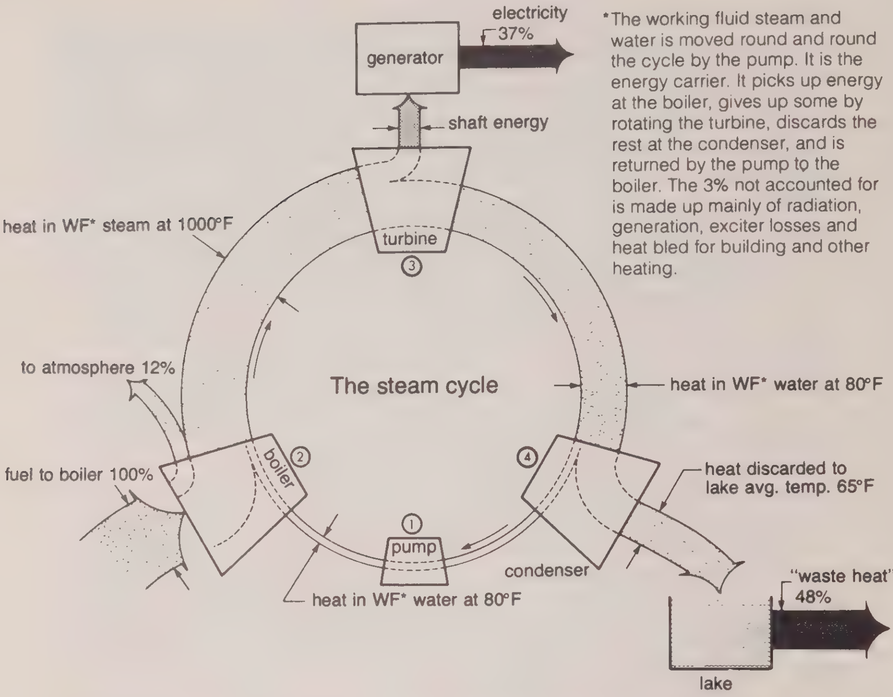


Figure 2. Energy flows in a fossil-fuelled power plant. (Source: Ontario Hydro)

generator. When the steam leaves the turbine, it is considerably reduced in temperature and pressure, but is still quite hot. A heat exchanger is used to cool it and condense it back into water. This water is then pumped back to the boiler, where it can be turned into steam again and run once more through the cycle.

A modern fossil-fuelled generating station may convert up to 40 per cent of the energy in the fuel into electricity. A nuclear generating station may convert up to 29 per cent of the energy in the nuclear fuel into electricity. The remaining 60-71 per cent of the energy released from the fuel in a thermal generating station is discharged to the environment. In the fossil-fuelled power plant, about 12 per cent of this heat goes up the chimney (see Figure 2). In both fossil and nuclear plants, however, all of the heat that must be removed from steam to condense it back to water is discharged into a cooling water system. Because the nuclear plant requires more fuel energy per kilowatt generated, and sends no heat up the

smokestack, it discharges about 75 per cent more heat into the cooling water than does a fossil-fuelled plant with the same electrical capacity.

There have been few complaints about the heat associated with the smokestacks of fossil-fuelled power plants. The potential environmental problem with thermal pollution arises from the enormous quantity of warm water that is discharged from the plant into a lake (for all Ontario Hydro plants) or river. The cooling water that is used to condense steam back into water is never, itself, close to boiling. The temperature of the water that passes through the plant may be raised by about 10°C. There is generally no change in the chemical composition or other properties of the water that passes through the cooling cycle, apart from (in some cases) a reduction in the quantity of dissolved oxygen in the water.

An important reason for the concern about the thermal pollution of lakes and rivers by generating stations has been the disruption of aquatic life that it causes. Most species of fish and water plants are rather sensitive to the temperature of the water they live in. A permanent and substantial increase in the water temperature in a particular area, such as at the outlet from a cooling channel, can alter the species of fish and water plants that will be found there. The warmer water may interfere with the activities of fish requiring colder water, and some species may then be eliminated from the area. Fish such as trout, which tend to prefer cool waters, are prime game fish, while warm-water fish such as carp or catfish are regarded by some as less desirable. So even a change in the fish population may be considered undesirable.[3] If a generating station is used for peaking power and therefore operates only part of the time, there may be few forms of aquatic life that can adapt to the variations in water temperature that occur near the discharge pipe.

Warm water also encourages the growth of particular types of algae. Heavy growths, or "blooms", of algae in the summer can constitute a serious pollution problem, and increases in water temperature may aggravate this problem. Finally, fish and other forms of water life may be pulled through the cooling system of a power plant by the water currents. This is likely to be fatal to them, since few fish can survive a sudden sharp rise in temperature. Special measures may be required to prevent fish from entering a cooling system.

The effects of warm-water discharge also depend on the way the water is discharged. If it is discharged near the shoreline at the surface of the lake, organisms that live in these shallow waters are

directly affected. The warm water on the surface tends to lose its heat to the atmosphere rather quickly. If the water is carried offshore a mile or so and discharged on the bottom, there will be fewer immediate effects on aquatic life, since the population density is lower there than in shallow water. However, the heat will be trapped underwater, and it will be dissipated more slowly there than at the surface. Also, the warm water may rise to the surface, stirring up the lake in the vicinity of the discharge. Such a disturbance of the normally stable layers of lake water may be at least as damaging to aquatic life as a near-shore discharge.

Much of the concern over thermal pollution has arisen in the United States, and we must consider whether the problem is as important in Canada's cooler climate as it is there. In fact, there are those who argue that thermal pollution may be beneficial. It has been suggested that the locating of numerous power plants along the St. Lawrence River could sufficiently warm that river to extend the Great Lakes Seaway navigation season, which at present is closed during the winter months because of ice. Other studies have shown that it may be economical to raise species of fish that thrive in warm waters in special fish farms located at the outflows of the cooling water from a power plant.[3] In areas of Ontario where the water recreation season is short because of low water temperatures, it might be possible to utilize waste heat discharge to extend the seasons.

It would be a boon if the efficiency of thermal generating stations could be increased above the 30-40 per cent range that is now possible, and the amount of waste heat discharged correspondingly reduced, but experts seem to agree that there is little prospect in the near future of any substantial change in the efficiency of fossil-fuelled stations and that nuclear efficiency will grow only slowly.

Once the waste heat has been carried away from a power plant, it cannot be eliminated, but only moved from one medium to another. In other countries, the problem of the thermal pollution of water has been solved by directing some of the waste heat into the atmosphere, using large cooling towers, instead of into lakes or rivers. What happens inside a wet cooling tower is like what happens when air is blown through a hot shower; as the hot water passes through the air, some of it evaporates and the rest is substantially cooled. The heat that was in the water is transferred to the atmosphere. In addition, some of the water evaporates, so the atmosphere becomes more humid than it was. Thus, while

cooling towers can reduce the temperature of the water that is returned to a lake or stream, they do so by increasing the temperature and humidity of the atmosphere around the generating station. The construction and operation of cooling towers is rather expensive.

It should be noted that, while cooling towers may reduce a water pollution problem, they may also create an air pollution problem. During the summer months, Ontario residents might feel that making the atmosphere still hotter and more humid would be undesirable and in itself a form of pollution. In winter, the evaporating water can form fog, which may reduce visibility, or, if it condenses on road surfaces, create traffic hazards. In addition, the towers are enormous structures and might be regarded by some as ugly. Finally, since some water evaporates, it must be replaced, and the minerals in the replacement water must be separated and disposed of to avoid clogging the system.

Another approach to the problem of waste heat from generating stations is to search for productive uses for it. One such use is district heating; pipes carry hot water from a generating station to a nearby residential or commercial area where it is piped into buildings for space heating and water heating. District heating from generating stations has been used successfully in other countries. It presents problems, however. It lowers the efficiency of the generating station, the pipes are very expensive to install and maintain, and much of the heat can be used productively only in the winter. Differences in heating requirements and population density between Ontario and Europe make it difficult to predict the economics of district heating here, although in some cases it may prove economical.

There seems to be no simple way to dispose of waste heat. It remains a question whether it should be concentrated in water or dispersed in the atmosphere, and whether some of it can be put to use. A consideration of local conditions may be necessary to determine what is preferable in each case.

Environmental Issues of Nuclear Power

Canadian nuclear reactors use natural uranium, which is mostly

U-238, with some U-235, a fissile material. The uranium is processed into specially shaped elements which, when placed close to each other in a nuclear reactor, bombard each other with atomic particles, causing nuclear fission. During fission, the U-235 may be converted into various other elements, and some U-238 is converted into plutonium-239. The fission process gives off heat that is used to produce steam, which then powers a conventional generating turbine.

Because the process of producing steam from nuclear energy is quite different from that of producing steam by burning fossil fuels, the environmental problems are also quite different. A nuclear reactor does not emit vast quantities of hot gases to the atmosphere; it only discharges small quantities of air that has been used for ventilation. On the other hand, nuclear fuel presents environmental problems in mining and in transportation (as do coal and oil, in difficult regions), and the used fuel that is removed from the reactor is still hazardous and must be reprocessed or stored securely for long periods. Therefore, we must consider not only the environmental problems of operating a nuclear power plant, but also some of the problems of mining, processing, storing, and disposing of the fuel.

Much of the uranium for Canadian nuclear reactors is mined in the Elliot Lake and Bancroft areas of Ontario. Uranium is only a small part of the ore that is mined, so huge volumes of earth and rock must be processed to obtain a small amount of refined uranium. The usual water pollution problems associated with the mining of low-grade ores are present (silt, acid, and chemicals deposited in nearby streams and lakes). In addition, uranium mining may release small quantities of radioactive matter (radium) into the nearby waters, increasing the radioactivity of fish, and of the water. So far, water-borne radioactivity has not been shown to be a hazard to human health.[4]

Forced ventilation systems are used in deep mines to reduce the level of radioactive particles in the air to which miners are exposed. Unless the mine exhaust is carefully filtered, there may be some emission of radioactive particles into the atmosphere.

Uranium ore, called yellowcake, must be refined into uranium dioxide. The refining process creates solid waste that still contains some radioactive materials. If this waste is not treated carefully, radioactive particles may be washed into streams by rainfall, or blown as dust through the air. The discovery of high levels of radioactivity in Port Hope indicates some of the problems that can

arise from fuel processing. Here, radon gas, which is a decay product of radium, had escaped from dumps, and some radioactive decay products were found in construction materials. It should be possible, in principle, to minimize these emissions by using strict waste-control measures.

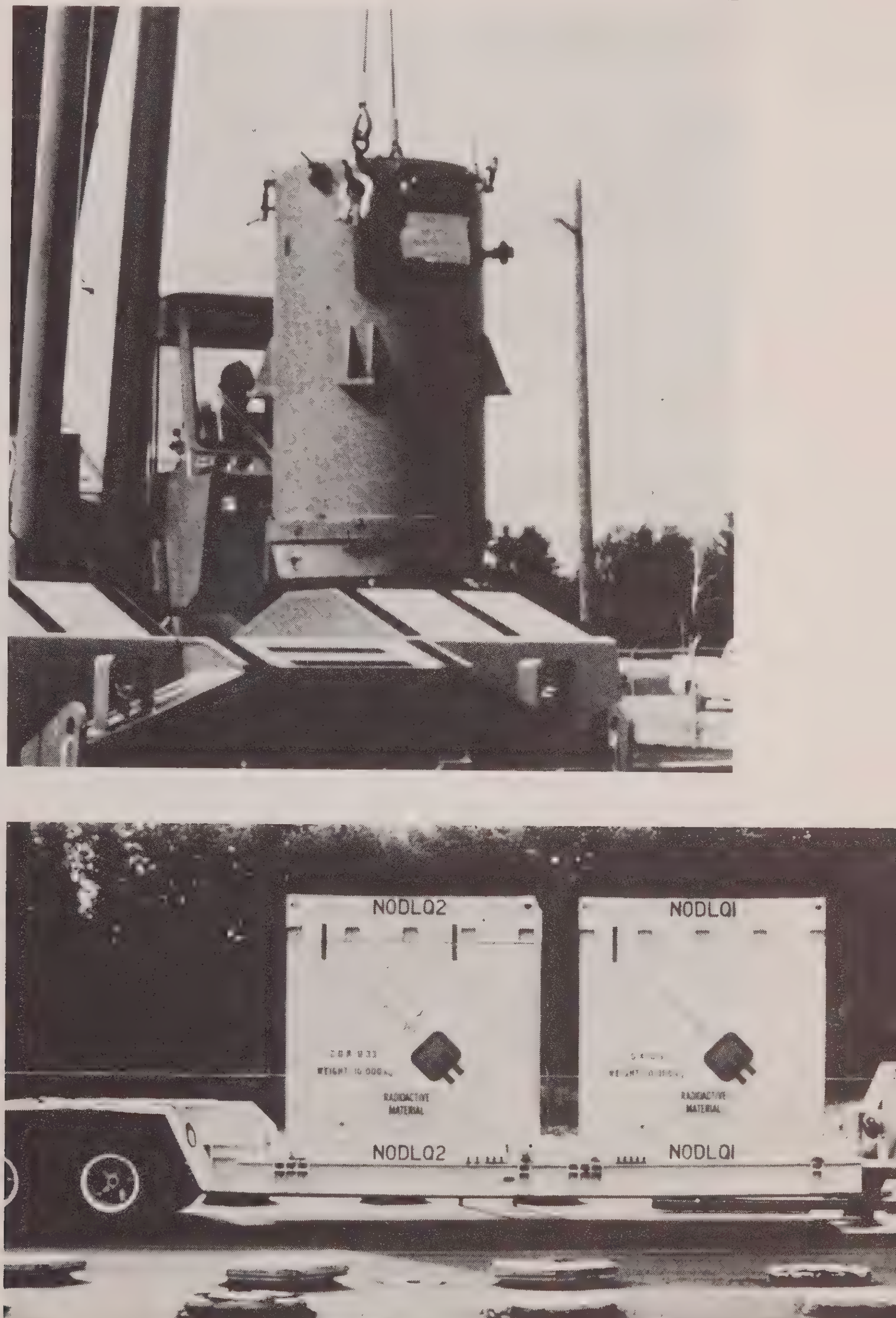
When used fuel is removed from a reactor, it may be reprocessed to salvage the remaining radioactive elements and concentrate them for use in new fuel elements. If fuel reprocessing plants are set up in Ontario (there are none now), they will present the possibility of highly radioactive elements being released into the air or water. In principle, careful design and operation of such plants should minimize this problem.

At some point, nuclear fuel becomes unusable for further power generation or reprocessing and must be disposed of. Also, some reactor parts that have to be replaced will be radioactive. Since used fuel and used parts may remain dangerously radioactive for many years, it is necessary to devise storage methods to contain them and their radioactivity for decades or even centuries. Experiences in other countries suggest the problems that are involved in finding locations and protection methods that will ensure that no dangerous radiation will escape in the foreseeable future.[2, 5]

Until now, used fuel has been placed in storage bays at the sites of generating stations. It is anticipated that during the 1980s these storage facilities will become full and the fuel will have to be moved. The present plan is that all fuel will be held in water-filled tanks at the generating stations for 10 years, during which time the material will become substantially less active, in radiation and/or heat discharge. The fuel will then be shipped to a central "interim storage facility" to be either reprocessed or packaged for disposal. It may remain there for 25 years. Finally, the fuel will be moved to an "ultimate disposal facility" where it will be buried deep in a stable rock formation. The selection of this ultimate disposal site is important, since the fuel will continue to generate potentially dangerous radiation for thousands of years.[11] No interim storage facility or ultimate disposal site has been constructed to date.

The transporting and storage of radioactive nuclear fuel and wastes raise the possibility that vandals or terrorists might gain control of some dangerous material and accidentally or intentionally release large amounts of radiation, or perhaps even build an explosive device. Therefore, the plan for handling spent fuel must include safeguards against any misuse of such materials.

The spent fuel storage bays at the Pickering nuclear generating station. (Source: Atomic Energy of Canada Limited)



Some of the elaborate equipment that is being tested for use in the storage and transportation of radioactive waste materials. (Source: Ontario Hydro)

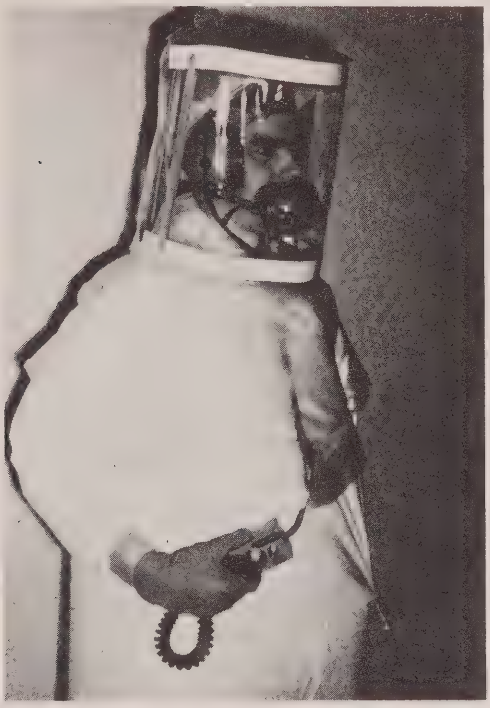
Canadian nuclear reactors use "heavy water" (deuterium) as a moderator in the reactor to ensure satisfactory fission using natural uranium fuel. Heavy water is extracted from lake water by a process involving large quantities of hydrogen sulphide. In normal operation, small quantities of hydrogen sulphide are present in the waste water from the plant, although the concentration is not high enough to affect fish. Hydrogen sulphide could also be emitted as a gas but in practice it is first burned to sulphur dioxide and then released in a tall smokestack. It is expected that ground level pollution from these emissions will not be substantial unless there is an accident in the plant (considered unlikely) in which case high ground level concentrations of the gas, exceeding provincial criteria, could result.

In normal operation, a Canadian nuclear reactor emits small amounts of radioactive material into the air through the ventilation system, and into the water through the cooling system. The Atomic Energy Control Board, which is responsible for public health and safety regarding nuclear power, has set limits on the radiation to which the public may be exposed from the operation of nuclear reactors. These limits are based on research into the effects of radiation on health, conducted by many bodies in various countries, and are reviewed and revised from time to time. Efforts to limit the emissions have in most cases kept the radiation levels at Canadian nuclear reactors to below one per cent of the federal safety limit.[10] In the event of a major accident at a reactor, radioactive emissions to the air and water might increase greatly. While it is estimated that a major accident releasing large amounts of radiation is unlikely, this remote possibility must be considered as a potential environmental problem of nuclear power generation.

In addition to radioactive releases, nuclear reactors release large volumes of heat in the cooling water. The effect and control of this heat discharge has already been discussed.

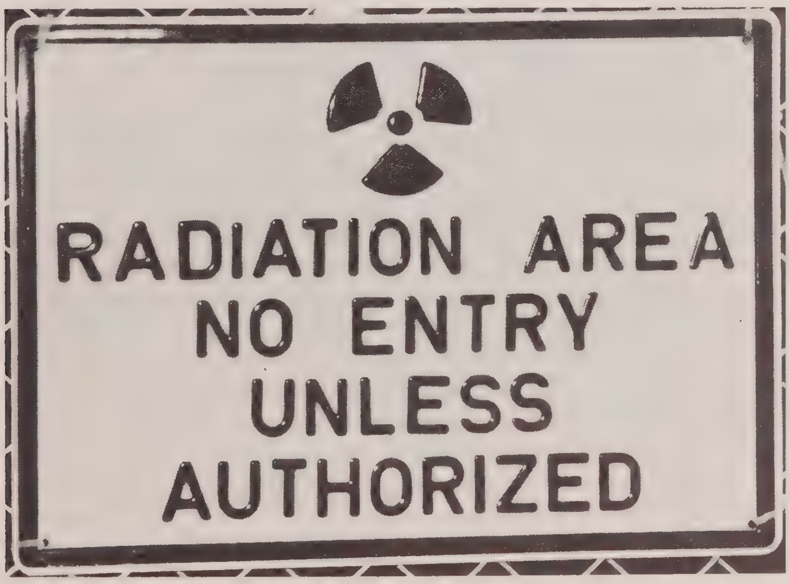
Health Effects of Nuclear Radiation

We have seen that threats to human health may arise from the nuclear power cycle in two ways. Radiation may be emitted directly into the atmosphere, exposing the entire body to a dose of radiation. Alternatively, radioactive particles may be emitted to the air or water or soil, and an individual who is in close proximity to



Left: An example of workers' protective clothing designed for use in nuclear generating stations, when required. (Source: Ontario Hydro)

Below: Precautions must be taken in nuclear generating stations to prevent contamination by radiation. This warning sign is in the Bruce generating station. (Source: John Neate)



such particles may receive a whole-body dose. If a particle enters the respiratory or digestive tract, or becomes lodged in the skin or clothing, then the primary concern is for the intense radiation to which the area near the particle is subjected, rather than for the whole-body dose.

Some types of radiation, called alpha particles, travel only very short distances – a few inches in the air and less than 0.01 inches in body tissue. Such radiation could cause local internal damage but not whole-body damage – or external damage, since the particles would probably not penetrate the outer layer of dead skin. Beta particles and gamma radiation travel much farther than alpha particles and are therefore potential sources of internal as well as external damage.

Canadians are already exposed to some radiation from both natural and man-made sources. The degree of exposure is measured in "rem", or thousandths of a rem (millirem). We are bombarded by natural radiation from cosmic rays and from small amounts of radioactive materials in the soil and water. The average person is exposed to man-made radiation from the fallout from atomic tests, diagnostic X-rays, nuclear power, and miscellaneous other sources. Table 1 shows an average level of exposure for North America, measured in millirem per year. The actual natural radiation will depend on elevation (the higher you are, the greater the exposure to cosmic rays), local soil conditions, and diet. The man-made radiation comes mostly from medical X-rays, such as dental X-rays and chest X-rays. If you have had no medical X-rays for a year, your medical dose is zero.

The average annual exposure of Ontario residents to radiation from Ontario Hydro's nuclear reactors is calculated by Ontario Hydro at 0.003 millirem. Clearly, this exposure from normal reactor operations is negligible compared with other sources. The Atomic Energy Control Board has adopted the standard of the International Committee on Radiological Protection for a safe maximum radiation dose for the general public, which is 500 millirem (0.5 rem) per year. Current average exposures are far below this level.

What are the probable effects of a small increase in the radiation to which Ontario residents are exposed continuously? Such a dose is called a "chronic" dose and its effects are difficult to predict, because the expected average increase in the dose caused by nuclear generating stations is a small fraction of the total current exposure. Studies suggest that the primary effects of a significant increase in exposure would be an increase in the occurrence of

Table 1. Radiation Exposure (millirem per year)

Natural radiation	
Cosmic rays	44
Internal dose (food, water, air)	18
External dose (soil, rocks, etc.)	40
Total natural radiation	102
Man-made radiation	
Fallout from atomic tests	4.0
Medical X-rays	72.0
Radiopharmaceutical therapy	1.0
Nuclear power	0.003*
Miscellaneous and occupational	2.8
Total man-made radiation	80.0

*From Ontario Hydro estimates.

Source: National Academy of Sciences, Washington.

leukemia, other blood disorders, bone cancer, lung cancer (most likely as a result of breathing radioactive dust), and thyroid cancer. Because only a few of the persons exposed to low-level radiation would contract any of these diseases, the effects of radiation are often expressed as the change in the occurrence of a disease resulting from a given exposure. At current levels of exposure, it would not be possible to observe changes in the occurrence of these diseases resulting from the operation of nuclear generating stations.

In addition to the threat to the exposed individual, there is also the danger that his or her future offspring may be affected. Radiation can affect the gene composition of chromosomes, increasing the likelihood of mutations in the next generation and even in later generations. It is usually assumed that any such mutation will be an unfavourable one, causing a deformity, an incapacity, or some life-shortening weakness. While it is difficult to predict the genetic effects of radiation, one U.S. study found that the worst accident that could occur in a nuclear reactor would increase the normal mutation rate by only 2 per cent.[19] Genetic

risks from chronic low-level exposures are estimated to be very small.

A major question concerning the effects of nuclear radiation on health is whether or not the effects are proportional to exposure. Some argue that if the exposure is multiplied by 10, the effects may be multiplied by more than 10, because the body can repair minute damage from low doses, but not damage from greater doses. If this is true, then we should worry less about small increases in background radiation. The point is in serious dispute, however, and many authorities regard any increase in radiation levels as likely to increase disease rates, and therefore undesirable.

Suppose there was an accident at a nuclear plant that released massive amounts of radioactive material. (Studies suggest that such an occurrence is very unlikely. In fact, with the CANDU reactor an accident that could release large amounts of fuel suddenly may be impossible.) There would not be a nuclear explosion, but rather a steam or chemical explosion that might release some of the radioactive fuel. Persons nearby might experience an acute (short and severe) exposure. There would be vomiting and nausea, followed by sore throat, hemorrhaging, diarrhea, and other evidence of damage to the gastrointestinal tract. The blood-forming process would be dramatically impaired. Death might follow within a year. Such effects could only be expected in persons close to a major radioactive accident at a nuclear site.[2]

A study was undertaken in the United States to determine the probability of accidents at nuclear reactors and the consequences of such accidents in 1980, when about 100 reactors will be operating there.[19] It was concluded that the chance of a serious (radiation-releasing) accident in any one year will be 1 in 200. Furthermore, of the 15 million persons living within 25 miles of a reactor, two fatalities and 20 injuries could be expected each year from the reactors. For comparison, it is noted that the same population could expect 4,200 fatalities and 375,000 injuries from automobile accidents, 1,500 fatalities and 75,000 accidents from falls, 560 fatalities and 22,000 injuries from fires, and eight fatalities from lightning. The risk of serious accidents at Canadian reactors is probably less than in the U.S., and the exposed population here is far smaller.

Another study concluded that the average U.S. exposure to radiation from the nuclear power industry could remain below one millirem per year (one per cent of the fatal average national dose per year) if: (a) anticipated engineering performance is achieved,

(b) wastes are adequately managed, (c) there is no sabotage or theft of fissionable material, and (d) there are no catastrophic accidents.[8]

Environmental Problems of Water Power

While water power is generally thought of as a natural, clean, and not harmful means of generating electricity, further expansion of hydro-electric generation in Ontario would have a number of environmental consequences that might be important in evaluating such projects.

Many of the remaining feasible hydro power sites are on rivers that are important for the life-styles of native people, or are valuable as wilderness areas or for canoeing. The damming of such rivers may require the relocation of native settlements, may destroy native hunting or fishing areas, and may eliminate scenic rapids and gorges. The opportunity for canoeing on a challenging white-water river might be eliminated. The natural wilderness along the river might be transformed as the river became a reservoir. In many cases, the demand for power would not coincide with the river's rate of flow, so the level in the reservoir would fluctuate greatly, leaving unsightly areas along the shore that would not be attractive for recreation. While Ontario has tremendous water resources, the number of clean rivers suitable for use by native people or for recreation is limited, and each one that is dammed is lost forever.

The construction and operation of a power dam may greatly affect the level and flow of a river. Above the dam, of course, the depth of the water is increased, increasing the amount of water that soaks into the earth. The surface area of water is increased, increasing the water loss through evaporation. Thus, the total amount of water in the river below the dam is decreased. Downstream, the flow of the river is regulated. Seasonal variations in flow are usually reduced or eliminated. They may be replaced by variations in flow related to daily or seasonal variations in the electricity demand. Suspended matter in the river will tend to settle out in the reservoir, reducing the amount of such matter in the water for a short distance downstream from the dam.

The creation of a reservoir may improve the growing conditions

for a variety of plants and fish above the dam. This may result in an increase in some desirable species of fish. It may also result in abundant growth of algae and weeds that can make it difficult or impossible to use the reservoir for recreation. In any case, the plants and fish in the reservoir will be quite different from those previously found in the stream.

Other changes will occur downstream. A number of plants and animals that attach themselves to the stream bed will be favoured by the more stable flow of the river. If too extensive, such growths can become a nuisance. Migratory fish are usually destroyed by a major dam, although artificial means of transporting fish around the dam may enable some species to survive.

It should be clear that a hydro-electric dam can cause a number of changes in the environment, both upstream and downstream. Some changes are clearly undesirable; others may be beneficial. Only a careful study of each project can reveal what its effects will be.

The Future

Table 2 shows the quantities of fuel used for generating electricity in 1975, and planned for use in 1995. Coal consumption will quadruple in these two decades, oil consumption will be multiplied by seven, while the use of nuclear fuel will be multiplied by 17, according to the plan.

Table 3 shows the quantities of pollutants produced and released from each of the fuels used to generate electricity in Ontario in 1975, and projected for 1995. The quantity of particulates released is less than one per cent of the quantity produced, because of the high standard of pollution control. All coal-fired units have electrostatic precipitators, with design efficiencies of 99.5 per cent, and an actual efficiency that is thought to average 99 per cent after allowing for normal breakdowns and variations in operating conditions. Oil-fired units have electrostatic precipitators with design efficiencies of 95 per cent.[11]

The second half of Table 3 shows the quantities of pollutants projected for 1995 if generation grows as expected. Particularly noteworthy is the increase in spent radioactive waste attributable to the large anticipated growth in the use of nuclear energy for generating electricity.

Table 2. Fuel Consumption in Electricity Generation in Ontario 1975, 1995

	Coal (million tons)	Residual oil (million barrels)	Gas (billion cubic feet)	Nuclear (metric tons)	Water power
1975					
Fuel use[1]	7.6	1.3	55.7	25.3	—
(percentage of electricity from this fuel[2])	(24)	(1)	(6)	(13)	(39)
1995					
Fuel use[1]	28.7	10.0	49.0	44.84	—
(percentage of electricity from this fuel[2])	(21)	(2)	(1)	(66)	(10)

1. Source: Ontario Hydro.
2. Source: Ontario Hydro. Imports of electricity are not shown here, but they accounted for 17 per cent of electricity in 1975, bringing the total to 100 per cent.

Table 3. Pollutants Produced from Electricity Generation in Ontario, 1975, 1995 (tons per year)

Fuel	Coal	Oil	Gas	Nuclear
1975				
Pollutant				
Particulates produced	617,000	218	negligible	—
released	6,200	11	negligible	—
Sulphur dioxide	339,000	10,700	negligible	—
Oxides of nitrogen	76,000	2,800	10,900	—
Radioactive spent fuel	—	—	—	253,000
1995				
Pollutant				
Particulates produced	2,296,000	1,680	negligible	—
released	23,000	84	—	—
Sulphur dioxide	763,000	33,000	negligible	—
Oxides of nitrogen	287,000	21,800	less than 9,600	—
Radioactive spent fuel	—	—	—	4,484,000

Source: Emissions estimated from fuel use in Table 2, and the following assumptions:

Fuel:
- Coal — 1975: 10.15% ash, 2.35% sulphur
  1995: 10% ash, 1.4% sulphur
- Oil — 1975: 2.5% sulphur
  1995: less than 1% sulphur

Emission factors:
- Coal — ash – 16 lbs per ton of coal burnt
  sulphur – 38 lbs per ton of coal burnt
  NO – 20 lbs per ton of coal burnt
- Oil — ash – 8 lbs per 1,000 U.S. gallons
  sulphur – 157 lbs per 1,000 U.S. gallons
  NO – 104 lbs per 1,000 U.S. gallons

Pollution control: particulate control efficiency
Coal 99%
Oil 95%

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Alternative Power Generation Technologies

Robert K. Swartman

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The traditional source of electricity for Ontario Hydro is the hydro-electric power plant. Since 1945, good sites for new hydraulic plants have rapidly become fewer, and farther from the areas requiring additional quantities of electricity. Most of the sites in Ontario within economical transmission distance have now been developed. It has been necessary to develop a 500 kilovolt transmission line from the sources in northern Ontario to the area of large demand around Toronto. The only remaining hydro-electric sites are in the arctic watershed, and they are not deemed economical.

Because demand was continuing to rise, Ontario Hydro began, about 1950, to generate electricity from thermal power stations. These stations convert thermal energy into electricity. The thermal energy is obtained from the combustion of fossil fuels, generally coal, but more recently also oil and natural gas. Since 1960 a major program has been developed to use the heat released from the nuclear fission process to generate electricity.

There are other ways to produce electricity than hydraulic power plants, or plants that convert fossil or nuclear fuels into thermal energy. Other methods include windmills, photovoltaic cells, and tidal power. The pattern for unlocking energy can be shown on a triangle (Figure 1).

In some processes, as in a hydraulic power plant, stored energy (the potential energy of water) is converted in a hydraulic turbine into mechanical energy, which in turn drives an electrical generator to produce electricity. But in many processes, as in a thermal power station, stored energy (from uranium or a fossil fuel)

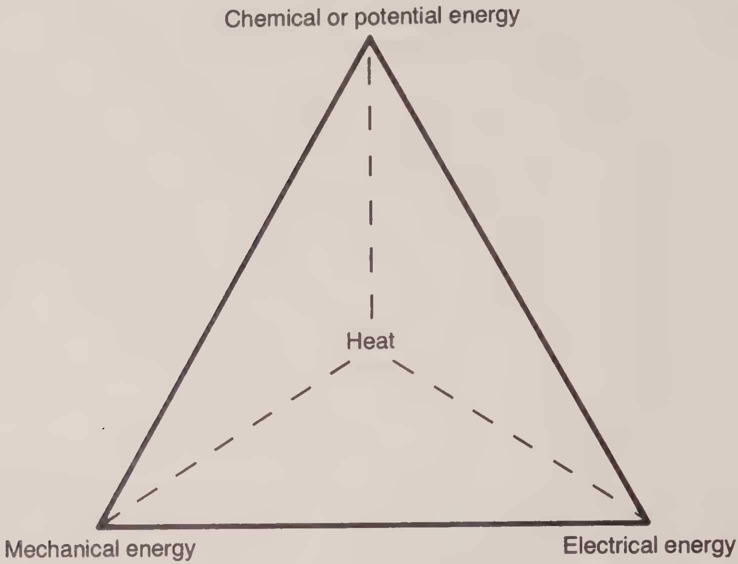

Figure 1. The energy triangle: the pattern for unlocking energy.

releases energy as heat, which is converted into mechanical and then into electrical energy. All energy conversion processes can be illustrated using the triangle.

It is important to distinguish between energy sources and energy conversion techniques. For example, the potential energy in water, and the chemical stored energy in coal, and the atomic bonding energy in uranium are all sources of energy. However, combustion and the fission process are means of converting energy from one form into another, as in a hydraulic turbine or an electrical generator or an automobile engine. The primary sources of energy are forms of energy that can be converted into other forms different from their natural ones. Coal, oil, gas, and uranium may require refining or some process to remove a contaminant, but they can be used directly in energy conversion. Hence, they are primary sources of energy. Hydrogen, on the other hand, does not occur naturally in large quantities. When hydrogen is being suggested as an energy source, in the concept of the "hydrogen economy", it is really an intermediate step between a primary source and an ultimate application. It is a form of stored energy. In the same vein, magnetohydrodynamics (MHD) is sometimes suggested as an energy source. It is, however, a method of converting energy from

a primary source to another form, such as electricity.

Once we have made the distinction between energy sources and energy conversion techniques, we should distinguish between capital, or non-renewable, sources, and income, or renewable, sources. The capital sources include fossil fuels (coal, oil, and gas) and nuclear fuels, and thus are like money in a bank account. They can be left unspent to gain in value as time goes on. The income, or renewable, sources of energy can be likened to interest on a bank deposit. They include wind, geothermal sources, tides, atmospheric electricity, biomass, hydraulic sources, the atmosphere, the ocean temperature gradient, the Earth's magnetic field, waves, and solar energy. Most of them depend on the sun, a renewable source. The renewable sources are continuously available; using them today does not affect their availability tomorrow. Generally, it is impossible to use them up, they are so diffuse. The power in the wind, in the waves, or in sunlight is small at any one location, but over a large area the energy available from each of these sources is immense.

In discussing conversion methods, I described the pattern for converting energy as a triangle. Whenever the pattern moves through the centre of the triangle, so that heat is released in the process, the laws of thermodynamics apply. The first of these laws states that all forms of energy are convertible, one form to another. The second law states that there are limits to the amounts of energy that can be converted from one form into another.

The French physicist Sadi Carnot published the second law in 1824. Carnot understood that thermal efficiency is limited by the maximum and minimum temperatures in a thermodynamic cycle, and he devised a way of calculating thermal efficiency. The thermal efficiency for the Carnot power cycle is:

$$\frac{\text{high temperature} - \text{low temperature}}{\text{high temperature}}$$

No thermodynamic cycle can be more efficient than the Carnot cycle and so the Carnot cycle is useful for the comparison of other cycles.

It is a lack of understanding of the second law that leads some people to think that, with a properly designed carburetor on their car, they could get the use of all the chemical energy stored in gasoline, instead of only 20 or 30 per cent of it.

The concepts I have described must be understood as background for the discussion of future possibilities that follows.

A Review of the Technology

Ontario Hydro has embarked on the utilization of all forms of capital, or non-renewable, resources. It has thermal power stations that are nuclear-fuelled, some that burn coal, and others that burn gas or oil. It is possible that the breeder reactor, or the use of thorium rather than uranium, will extend our nuclear fuel sources. But the using of a non-renewable energy source implies the depletion of that source, in time. Also, many people are alarmed about the possibility of accidental discharges of gaseous fission products, or the problem of disposing of the spent fuel, or the possibility of terrorists using the nuclear products or power stations in some kind of blackmail.

The idea of having some nuclear power stations is acceptable, but the idea of building nuclear power plants to meet an indeterminate growth in demand is less appealing.

Ontario Hydro is now using the capital sources of energy, and it also continues to depend heavily on its original source, hydraulic energy. If the demand for electricity continues to grow, even at a rate corresponding to the expected rate of population growth of 3 per cent per year, it will double in about 23 years. The present world growth rate of 2 per cent per year will double the world's population in approximately 35 years.

Many economic processes are based upon growth. A yearly 5 per cent increase in the Gross National Product (GNP) is considered healthy, while a one or 2 per cent growth rate is usually associated with a lagging economy. A constant 5 per cent growth rate yields a GNP that will be eight times its present value in three "doubling" periods (42 years). The energy consumed in one doubling period is approximately equal to the quantity consumed for all time prior to that doubling period. Ontario Hydro has recently announced a planned growth rate of 6 per cent per year. This rate has a doubling time of 11.6 years. In 11.6 years our demand will have doubled and during that period we will have consumed as much energy as in all previous time.

The calculation of doubling time is particularly significant when the consumption of a finite resource, such as fuel, is considered.[1]

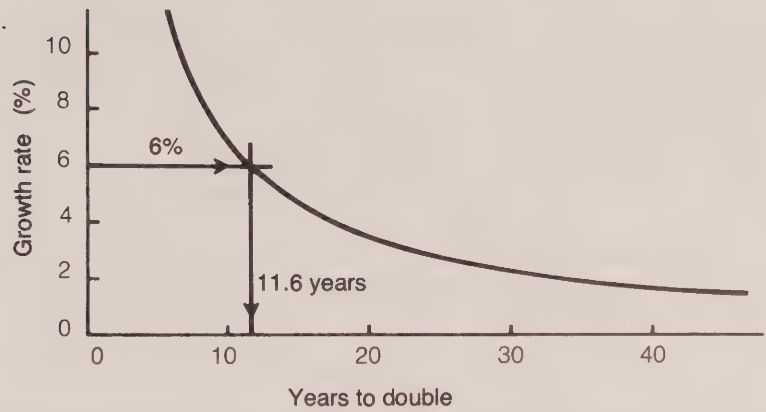

Figure 2. Doubling times for consumption of electricity for selected growth rates.

For a constant growth rate, the consumption in one doubling period is approximately equal to the amount consumed prior to the doubling period. If the end of a doubling period coincides with the total depletion of the resource, half of the resource must have been on hand at the start of the last doubling period. In the final doubling period, the final half of the initial reserve is depleted. Figure 2 shows the yearly growth rate plotted against years for doubling.

Rain and snow form rivers; the rivers are dammed to give a high potential head, so that the water flowing through hydraulic turbines converts the potential energy into mechanical energy; the hydraulic turbines drive electrical generators so that the energy is transformed into electricity. A typical hydraulic turbine/generator is sketched in Figure 3. The water continues down the river, perhaps to other headponds that supply more hydraulic power stations, perhaps to the Great Lakes or to salt water. An amount of water equivalent to what flows down the various rivers evaporates, and eventually comes back to the Earth as rain or snow, completing the "hydrologic" cycle.

The original source of energy for Ontario Hydro was hydraulic energy, which depends on the hydrologic cycle, which, in turn, gets its energy from the sun. It is a renewable source, but it can be used only where the topography and climate combine to create a suitable site. Most of the suitable sites in Ontario are being used.

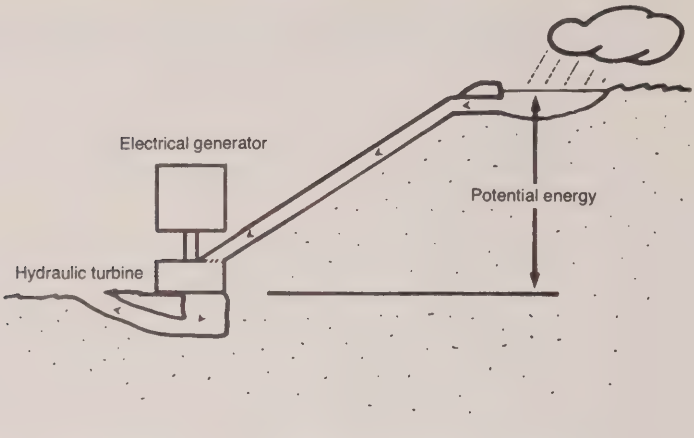

Figure 3. Sketch of a typical hydraulic generating station site.

Certainly the good sites in the southern part of the province are all being exploited.

Some sites have been modified in recent years to make them more efficient. The only remaining sites that could be developed for economical power are in northern Ontario. They are at such a distance from the load centres that their development is unlikely. In any case, the additional energy they could supply is only a fraction of the need as our demand increases.

Solar and wind energy and biomass have been used for centuries. The wind was first harnessed about 3000 B.C. to drive ships. Wood and agricultural products have been used to keep man warm for many centuries. Wood was once used to power manufacturing plants and locomotives. It is interesting to note that, up to 1972, Canada obtained more energy from wood than it did from nuclear fuel.[2] Until recently, solar energy was used to dry grain, clothes, and hay, and it is so much a part of our lives that we tend to overlook it. The fossil fuels that we use so wantonly originated with the sun. They represent energy that has been trapped and has remained stored for millions of years. Our climate, the wind, and biomass are all produced by the sun. Even our moods are influenced by the sun. Recent research has shown that people working in artificial illumination show a psychological improvement when the lights are adjusted so that the spectrum is close to that of the sun.

The sun has been used in direct ways. The Greeks repelled the Romans in 212 B.C. by using mirrors to concentrate sunlight on the

ships of the enemy. The ships apparently caught fire with the intense heat. In more recent times, some of the historical landmarks in the harnessing of solar energy include: a still in Chile, about 1872, that provided fresh water for a mine from brackish water; an engine in Arizona, about 1904, driven by a conical concentrator; a large collector and engine built in 1912 in Egypt; and the use of solar cells on the spacecraft of the 1960s to provide on-board electricity.

A large grant to the Massachusetts Institute of Technology in 1937 provided a stimulus for research in solar energy that continued until about 1955. Professor Hoyt Hottel was the project leader and he is now regarded as the "senior statesman of solar energy". He advises that solar energy should be treated with cautious optimism.[3] His project was concerned primarily with house heating, so his comments were aimed at that application of solar energy. When we consider that heating takes about 35 per cent of our energy load in Canada, it seems that, if solar energy could provide even 50 per cent of the heating load of our houses, it might enable us to save 17 per cent of our national energy load.

It is important to understand the relationship between the quantity of heat energy demanded in various applications and the temperature at which the heat is used.[4] Figure 4 shows this relationship. The thermodynamic term for the temperature at which energy is used is "availability". The availability of low-

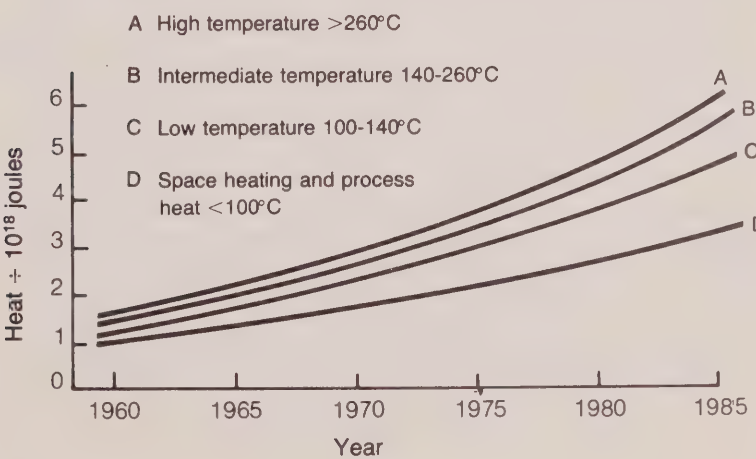

Figure 4. Graph showing the relationship between the quantity of heat energy consumed in Canada (projected to 1985) and the temperature at which the heat energy is used.

temperature energy is less than the availability of energies at higher temperatures. Electricity, which can be converted into other forms of energy, is 100 per cent available, because it is not dependent on temperature. It seems wasteful to convert an energy source into heat and eventually into electricity, and then back into heat. The thermal efficiency in converting the source into electricity is, typically, not higher than 40 per cent, so converting the electricity back into heat, even at 100 per cent conversion, results in a heat recovery from the source of less than 40 per cent. If the source is used as heat directly, the conversion efficiency could be as high as 80 per cent. There seems to be a need for us as a society to become more discriminating in our use of energy. We should not use high-grade energy for a low-grade application. We should use low-grade energy for low-grade applications, where possible.

If we want to pump water, it seems reasonable to use a windmill-driven pump that depends on a renewable source. Although the price of electrical energy may be only a few cents per kilowatt-hour, this price may not represent the true cost of the energy. Even if the price does reflect the cost today, if it depends on a non-renewable source of energy there should be some consideration in the price for the replacement value of the energy. Typically, this depletion allowance for fossil fuels is given to the company that extracts the material from the ground, not to the population that will be deprived of the use of that resource when it has been depleted.

Our present supplies of energy include substantial amounts through hydraulic power plants, a renewable source, and from fossil fuels and nuclear fuel, both non-renewable. There is great concern now, as a result of the knowledge that we may run out of oil and gas in Canada in 20 or 30 years.[5, 6] Exactly when, is not known, because we do not know the exact size of our reserves, and it is difficult to predict our demands. If the laws of supply and demand are allowed to prevail, the price of oil will increase so much that we will no longer be able to afford it before the time it is depleted.

The United States has shown more concern than any other country about future supplies of petroleum, probably because it is so heavily dependent on this fuel. A task force was formed there early in the 1970s to consider solar energy as a national resource. Its report, in December 1972, recommended the allocation of money for research on solar energy.[7] Subsequently, energy became such an important issue to the U.S. government that it created a new

agency, the Energy Research and Development Administration (ERDA), to co-ordinate energy research and development and to demonstrate the feasibility of various forms of energy,[8] particularly solar energy.[9] ERDA has predicted the energy demand in the U.S. and the amount that will be supplied by solar energy in the future (see Figure 5).

It is apparent that the Americans are very serious in their plan to become energy-independent. They are putting millions of dollars into research on non-renewable resources. They are also spending millions on demonstrating the feasibility of using solar energy for space heating and cooling. Combined with the Housing and Urban Development Agency (HUD), ERDA is involved in building hundreds of demonstration buildings and encouraging business, large and small, to become involved in this field. Such government activity is intended to reduce the usual 20-year period between proof-of-concept and commercialization to less than five years. The U.S. program will undoubtedly have an effect on our energy supplies, because their developments in technology tend to be rapidly embraced on this side of the border. Solar energy is very attractive to home-owners because it gives them an opportunity to supply, themselves, some of the energy they need for heating. Energy research and development programs in the United States are very significant and should be carefully watched in Canada.

The Americans are not the only large petroleum producers to show concern for this dwindling resource. At an international conference on solar energy in 1975, the Saudi Arabian Minister of Petroleum and Minerals said:

> We all know that the so-called energy crisis, though these days it is no longer talked about, is still with us. We all know that the oil reserves and what we can discover in the future will not be enough to satisfy our energy demands except for a few decades, and will all diminish and deplete by the mid 21st century.
>
> In order to save our civilization there should be a substitute for this energy, and there is no answer to our demand except solar energy. Though we have a huge reserve of oil in this country, we encourage very much any scientific research to establish and find other sources of energy supplies. We do this because we believe that humanity could not be saved except through this route.

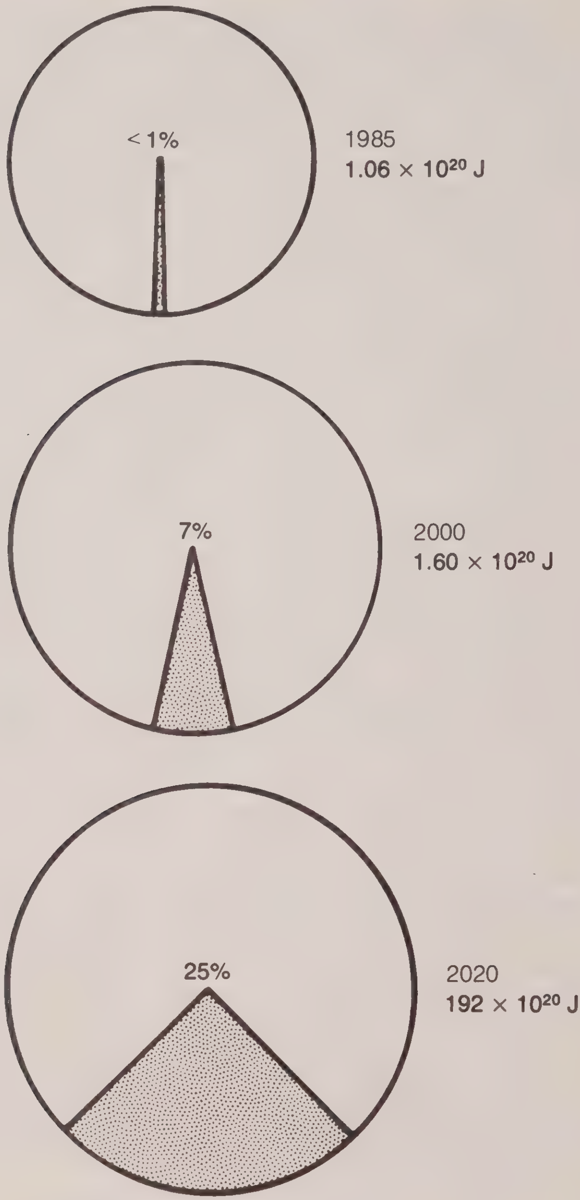

Figure 5. A prediction of future energy demands in the United States and the percentages that will be contributed by solar energy. (Source: *ERDA 49*, June 1975)

Energy from Fossil Fuels

There is obviously great potential in solar energy. But let us look at where we are today. The fossil fuels are usually converted into heat, then into mechanical energy, and then often into electricity. On the energy triangle, fossil fuels have potential energy. The hydrogen and carbon atoms are united with oxygen in the common process called combustion. The products of combustion are carbon dioxide, water, small amounts of carbon monoxide and nitrogen oxides, and heat. The heat may be in the form of a hot gas in the cylinders of an automotive engine, or it may be in a vapour such as steam, which will drive a steam engine or steam turbine. Because the process involves heat, the two laws of thermodynamics prevail. The first law states that energy can be converted from one form into another, while the second law restricts the amount that can be converted. This amount is approximately proportional to the difference in temperature between the source of heat (the hot fluid) and the cooler "sink" (usually lake water or the atmosphere) to which all of the heat in the process ultimately flows.

The amount of energy that is converted into useful work determines the thermal efficiency. The thermal efficiency is the useful effect divided by the heat required to produce the effect. Typically, the thermal efficiency of a large plant that burns coal to produce electricity is 40-45 per cent. This means that about 55 per cent of the heat released is wasted – not available for conversion into work because of the limitations of thermodynamics. Raising the temperature of the source or lowering the temperature of the sink increases the thermal efficiency.

No heat is involved in the conversion of energy in a hydraulic power plant. The process moves on the energy triangle from potential energy to mechanical energy to electricity. Another means of converting the chemical energy in fossil fuels into electricity, apart from combustion, is the fuel cell. The fuel cell combines oxygen and hydrogen or a hydrocarbon by means of a catalyst to produce electricity without any heat. The fuel cell was used in the Gemini series of spacecraft but has been too expensive for terrestrial applications and is not suitable for large-scale power generation.

Energy from Nuclear Fuels

The other major fuel for thermal power stations is uranium. Heat is released during the fissioning process, in which the uranium atom is split by a neutron acting as a projectile. In each fission, 2.2 neutrons are released, which causes a "chain reaction". In a nuclear reactor, only one neutron is allowed to split an atom for each fission; otherwise the process would increase until the fissions and consequent heat release destroyed the reactor. The management of neutrons in a nuclear reactor is critical and is achieved by changing the level of the heavy water moderator (in a CANDU reactor) or by the use of neutron-absorbing materials such as cadmium. The heat released in the fissioning is conveyed in a vapour such as steam, which flows through a steam turbine to drive an electric generator producing electricity. Once the heat is produced, the processes are similar to those in fossil- and nuclear-fuelled power plants. The typical thermal efficiencies of nuclear power stations are generally about 3-5 per cent lower than for fossil-fuelled plants (i.e., 27-30 per cent). They are lower because the maximum reactor temperatures are lower – a maximum of 550°F for CANDU reactors, compared with 1,100°F for the Lakeview generating station, which burns coal. Higher operating temperatures, and hence higher thermal efficiencies, are conceivable in a nuclear reactor, but at present the safe limit is deemed to be about 550°F. Because the thermal efficiency is in the order of 30 per cent, 70 per cent of the heat generated by the fissioning is wasted. It is the large quantities of waste heat that make district heating attractive in the vicinity of large thermal power plants. Why not use the excess heat for heating houses and apartment buildings rather than rejecting it into a lake or into the atmosphere?

Converting Renewable Sources of Energy

The processes for converting energy from the following renewable sources can be illustrated on the energy triangle.

Wind Energy. The kinetic energy (mechanical energy) is converted into rotational energy, which is another form of mechanical

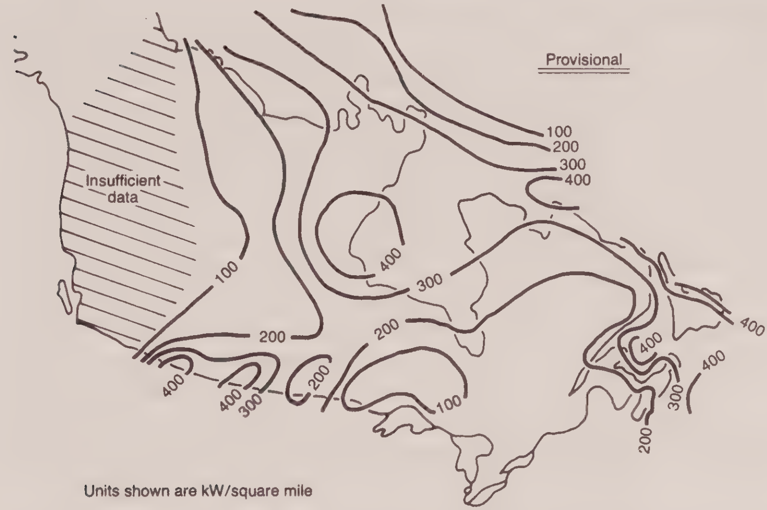

Figure 6. Estimated average wind power available in Canada. (Source: Ontario Research Foundation, November 1975)

energy. It can then be translated into linear motion for pumping water or used to drive an electrical generator. The sizes of wind-driven generators range from one-half kilowatt to hundreds of kilowatts. The wind-power profile in Canada is shown in Figure 6. A study of wind power was made in November 1975 for the Ontario Ministry of Energy and Ontario Hydro by the Ontario Research Foundation and the Electrical Research Association of the United Kingdom.[11]

Waves. Waves are produced by the wind, which in turn is produced by the sun. A considerable amount of the energy stored in waves is dissipated as the waves come crashing onto the shore. The potental energy between the crests and the bottoms of the waves can be converted by mechanical means into electricity. A study at the National Engineering Laboratory, East Kilbride, Scotland, determined that the United Kingdom could obtain half of its energy requirements from a series of wave-power generators that could be installed along the coasts of the Hebrides Islands. Considerable interest in wave power has also been shown in Japan.

Geothermal Energy. This is energy that is available because of the

high temperatures that occur towards the core of the Earth. Water in contact with the hot rock of the Earth's interior is heated and converted into steam. Natural geothermal sources occur where the continental crust is thin and there is greater geological activity. There are natural geothermal geysers and springs in Iceland, California, New Zealand, and the Canadian Rockies. There are no easily available geothermal sources in Ontario. It is possible to drill down to the Precambrian layer that underlies Ontario. This is at a depth of about 5,000 feet in western Ontario but it surfaces in eastern Ontario. However, the heat flow in the Precambrian layer is quite low – something like a million times less than solar radiation at the Earth's surface. Also, the porosity and permeability of this material is unsuitable for admitting water for steam production. If a hole is drilled deep enough, the temperature will rise and the heat flow will increase. There seem to be no locations in Ontario where this can be done for practical power production.

Fusion. This is the process that occurs in the sun and in a hydrogen bomb, by which hydrogen atoms fuse together to form helium with the release of considerable amounts of energy. To harness this source would require the containment of plasmas at temperatures of more than one million degrees Fahrenheit. Considerable research is being done on the use of lasers to achieve the necessary high temperatures and the magnetic fields to contain them. A vast amount of money is required for this research, and many experts doubt that the process will ever be practicable.[12]

Tides. The daily variation in the level of the oceans gives differences of potential energy varying from a few feet to approximately 50 feet in the Bay of Fundy. The potential energy is due to the difference in hydraulic head between low tide and high tide. The potential energy is converted by hydraulic turbines into mechanical energy and then into electricity. The only large-scale tidal power plant is at La Rance near St. Malo, France. Tidal power is used on a small scale to convert the tide's potential energy into mechanical energy that is used to pump water in the delta of the Pearl River in China,[13] and it was used at one time to grind grain in New England. The most suitable location in Canada is at Passamaquoddy Bay, New Brunswick. This site has been studied many times and always found to be uneconomical. The tidal power scheme is not feasible in Ontario because of the low tides on Ontario's salt-water coast of James Bay and Hudson Bay.

Atmospheric Electricity. This is energy that has been converted by friction between air molecules from kinetic energy into electricity. It usually manifests itself as lightning, accompanied by the noisy result, thunder. The area around Lake Nipigon is reputed to be one of the most active areas for thunderstorms. Atmospheric electricity represents a large source of energy but is of short duration and has not yet been harnessed. It is unlikely that it will ever be harnessed because of its transient nature.

Biomass. This is material that is the product of photosynthesis. It includes animal wastes as well as other agricultural products. It has been estimated for Ontario that 1.69 billion cubic feet of animal wastes are produced each year, which could be converted into the equivalent of 1.43 billion gallons of hydrocarbon fuel. Also, the estimated crop residues in Ontario of 3.8 million tons could be converted into the equivalent of 350 million gallons of fuel.[14] In some countries, India being an example, dried animal dung is burned as a fuel for cooking. The potential of converting animal manure into methane gas or of burning biomass such as straw is gaining attention and may become more attractive with time.

The energy of the sun enters the life cycle of every animal, bird, fish, and insect through photosynthesis, which produces the biomass of plants. No living animal is able to use solar energy directly in the metabolic process. They all depend on the stationary forms of life, the flora. There is renewable biomass that is surplus to the balance required for other forms of life and could be converted into liquid fuels. The Forestry Service of Environment Canada estimates that our "liqwood" fuel production potential appears to be about 2.5 times our current annual consumption of 206 million barrels of gasoline and roughly 110 per cent of our total current annual consumption of gasoline and fuel oil, which is now approximately 443 million barrels per year.[15]

The ERDA researchers in the U.S. expect that biomass will provide 5.5 per cent of the U.S. energy needs by the year 2020.

Wood, of course, is still used as a fuel in Canada. In fact, wood in 1972 provided one per cent of the primary energy supply, the same quantity as nuclear energy. Wood is biomass and it could be used as a fuel even more extensively than it is. The "energy plantation" concept visualizes the farming of trees for use as fuel.

Hydraulic Energy. This involves potential energy that can be converted into mechanical energy and then into electricity by

allowing stored water to fall to a lower level. As mentioned earlier, it is the basis on which Ontario Hydro was founded – to provide hydro electricity to the people of Ontario.

Atmosphere. The atmosphere is usually the low temperature heat sink to which all heat engines reject heat. Thermal power stations release heated cooling water into a large body of water, such as Lake Ontario. Eventually, equilibrium is restored as the heat is transferred, by mixing, into the lake water, and then into the atmosphere. In automobiles, likewise, the heat rejected from the engine, which is about one-third of the input energy, is dispelled in the atmosphere.

However, the atmosphere can also be a heat source. If it is possible to have a heat sink at a lower temperature than the atmosphere, heat will flow from the atmosphere into the sink. An air-conditioned building picks up heat due to the warmer air outside. A heat pump is a device for pumping energy from a low temperature to a higher temperature, as shown in Figure 7. There are a number of air-to-air heat-pump installations in Ontario. When the outside air temperature drops so low that the refrigeration compressor, which is the heart of the heat pump, cannot operate efficiently, most installations use electricity for supplementary heating. The heat pump has the advantage that, for medium temperature differences, more energy in the form of heat can be discharged than is used to drive the compressor. The electrical energy used to drive the compressor is added to energy already available at the lower temperature and provides energy at the higher temperature.

The atmosphere is used now as a heat sink on a grand scale, and as a sink for various pollutants. It is used in a small way as a heat source.

Ocean Temperature Gradient. This is a scheme to use the difference in temperature between the warm water at the surface of the ocean and the cooler water at some depth. The scheme was first demonstrated in 1929 by Georges Claude.[16] His equipment was destroyed by storms and his experiment is only now receiving further attention. A possible application of the concept for Canada would be to use the Arctic Ocean as a heat source and the cold arctic air as the heat sink.

Earth's Magnetic Field. There is a magnetic field shrouding the

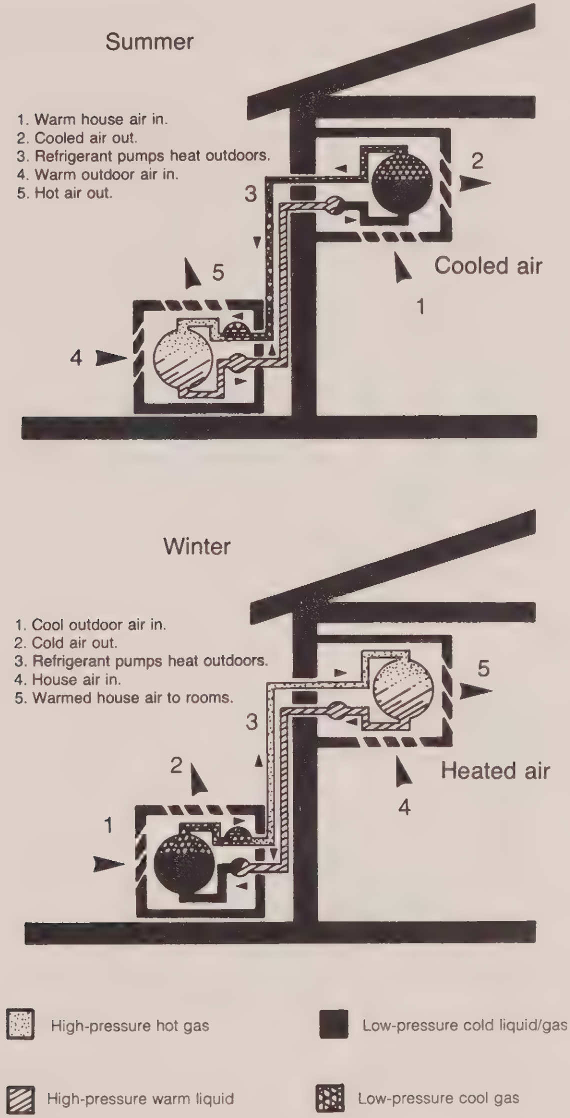

Figure 7. The functioning of a residential heat-pump system, summer and winter. (Source: Canadian General Electric Company)

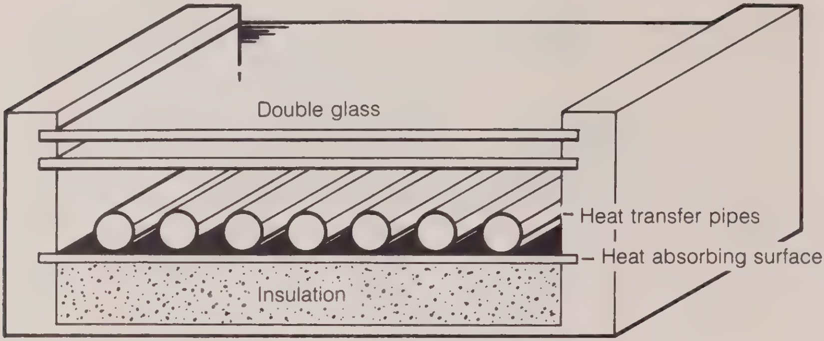

Figure 8. Diagram of a flat plate collector, used to convert solar radiation into thermal energy. The medium in the heat transfer pipes is usually water or air. (Source: Energy Probe, Toronto)

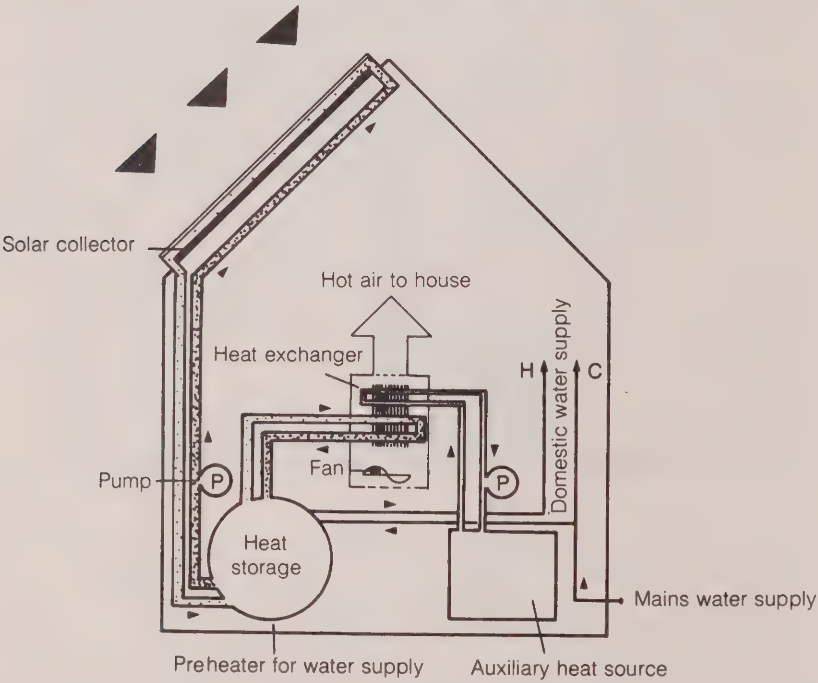

Figure 9. A typical residential solar heating installation, using water to store the heat and forced air to distribute it. (Source: Energy Probe, Toronto)

Earth. As the magnetic lines of force are crossed, an electromotive force is produced. This is the basis of a DC generator, which has a much stronger magnetic field than the Earth. Theoretically, electricity could be produced by crossing, or cutting through, the Earth's magnetic lines of force. However, it requires energy to move a body through the lines of force, and therein lies the problem. Electricity could be generated if a way could be found to cut across the magnetic lines of force.

Solar Energy. The sun is the source of all life on this planet. It is the driving energy for photosynthesis,[17,18] which provides food for the various orders of animals. It is also the driving force for wind, waves, atmospheric electricity, biomass, hydraulic sources, and ocean temperature gradient, and it keeps the earth at a temperature that makes it habitable by Man. The fossil fuels we use so extravagantly today have been stored for millions of years after being converted from the sun. The sun accounts for about 98 per cent of our energy supplies today – everything but nuclear reactor fuel. The sun itself is a great fusion reactor, in which hydrogen atoms fuse together to form helium, with an accompanying release of energy. The energy radiates into space, and this planet intercepts only a tiny part of it.

The energy arriving at the outer edge of the Earth's atmosphere covers a wide spectrum[19] from X-rays of 0.1 billionths of a metre wavelength to radio waves of 100 metres. However, 99 per cent of the sun's energy is contained between 0.28 and 4.96 billionths, and 38 per cent is in the visible light region between 0.4 and 0.7 billionths. Most of the ultraviolet radiation is absorbed by the ozone in the atmosphere. If this ozone were to disappear, the Earth would receive much more ultraviolet radiation. Hence the concern over the possibility that certain chemicals used as aerosol propellants might so reduce the ozone in the atmosphere as to weaken our protection against this damaging part of the solar spectrum.

So much has been written on solar energy in the last few years that it is difficult to keep abreast of the developments.[20] The greatest activity is in the U.S. where the Energy Research and Development Administration has established a Solar Energy Division with 15 branches.

The direct applications of solar energy that are of greatest interest in Ontario are space heating and cooling, solar thermal conversion, and photovoltaic conversion devices. The space heating and cooling can be accomplished with a flat plate collector,

as shown in Figure 8, which converts the solar radiation into thermal energy, with a conversion efficiency of 30-50 per cent.[21] The fluid circulating in the collector is heated to medium temperatures, around 150°F (65°C), and is available for space heating or to provide the energy required to operate a cooling system; or it can be consigned to storage for later use. A typical solar heating installation is shown in Figure 9.

The houses that have been built in the U.S. under the Solar Demonstration Act have cost $8 to $30 per square foot of solar collector. Generally, one square foot of collector is required for each one to two square feet of livable floor area. A house with 1,200 square feet would have 400 to 600 square feet of collector, oriented to the south at an angle to the horizontal equal to the latitude plus 15 degrees. This would add about $6,000 to the cost of the basic house – a target price that depends on a number of factors but should be achieved over the next few years.

There are probably a dozen houses in Ontario that have been designed as solar houses, some of which received government subsidy.[22] The Meadowvale Solar House in Mississauga received $70,000 from the federal Ministry of State for Urban Affairs as a part of the Habitat Conference in June 1976. The same ministry gave $90,000 to Provident House in King Township north of Toronto, which also got a grant of $50,000 from the Ontario Ministry of Energy. Another house that received support from the federal government was built near Gananoque by Larry South; it emphasizes energy conservation and uses solar energy combined with paraffin wax heat storage to provide part of the heating. The Ontario Housing Corporation sponsored a competition in 1975 that produced the design for a solar-heated senior citizens' house to be built in Aylmer.

Solar heating has been demonstrated to be technically feasible, as has solar cooling. The problem at the moment is the additional capital cost of installing the system. If life-cycle costing is used to analyse the economics, and a realistic inflation rate is assumed for energy costs, it is possible to justify a certain investment for the fuel saved. For example, if an inflation rate of 15 per cent is assumed for energy costs over a life of 20 years, and interest charges are 10 per cent, a capital investment of $400 is justified for each dollar of fuel saved per month at present values. In other words, if $20 a month can be saved on a fuel bill by installing solar heating, the justifiable capital investment is $8,000.

The usual argument against solar heating is that it costs too

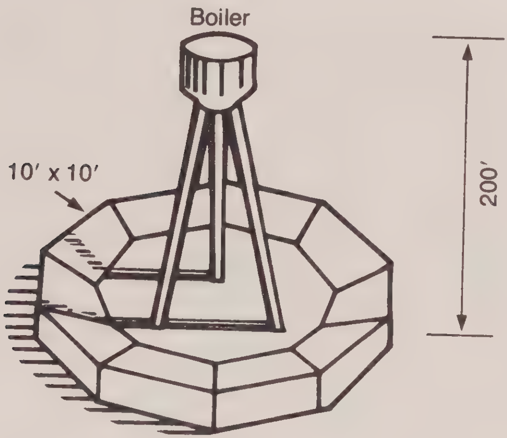

Figure 10. Diagram of a "power tower" being investigated in the United States for solar thermal conversion. Large mirrors mounted on the ground concentrate solar energy on the boiler to produce much higher temperatures than can be obtained with flat-plate collectors.

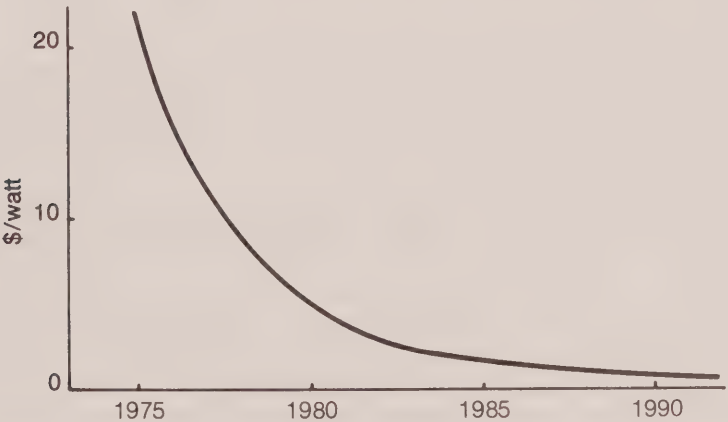

Figure 11. Graph showing expected trend in costs of photovoltaic devices.

much. It admittedly costs more to install than a conventional heating system, but the value of the fuel saved must be taken into account. Even if the economics showed no decided advantage, it might be that society, through government action, should encourage the use of solar heating because of the energy saved –

energy from fossil fuels that may be better used for more sophisticated purposes (i.e., the production of plastics). The U.S. report *ERDA 49* predicted that the contribution solar energy will make in the U.S. will be 7 per cent of the country's energy demand by the year 2000 and 25 per cent by 2020 (see Figure 5).[10]

Also, the U.S. expects to obtain more energy from direct thermal applications within 25 years than Canada used for domestic and farm applications in 1972. The comparison is rough, but the trends are apparent. If Canadians continue to assume that solar energy is a long-term proposition, certainly more than 15 years away, then there will be a self-fulfilling prophecy – except that solar energy will have such an impact in the U.S. that the technology will spill over the border, and the prophets of pessimism will be drowned in sunshine, or in the hardware for using it.

Solar thermal conversion utilizes thermal energy at higher temperatures than are associated with flat plate collectors. Concentrators can produce the necessary higher temperatures. One of the concepts being investigated in the U.S. is the "power tower" in sizes of up to 100 MW (see Figure 10). The mirrors would not have to be mounted on the ground but could be installed on rooftops or on vertical walls. An advantage of this concept is that power can be produced at the site where it is to be used.

The photovoltaic conversion is done by devices in which a surface effect stimulated by light produces electricity. The solar cells that produce electricity in Earth satellites and spacecraft utilize this effect. They have been so expensive that they could only be justified in space applications. But the U.S. ERDA project is sponsoring a large development program to bring the price down. Figure 11 indicates their expected trend in costs of photovoltaic devices.

We have been examining various renewable energy resources. Some have little applicability in Ontario, but others must receive serious consideration here. Although conservation is an essential part of any energy distribution scheme and may help us in the short term, solar energy and its near relatives, wind energy and biomass, are going to be needed eventually. If we assume that solar energy cannot or will not be developed for 15 or 20 years, then surely it will not be. If our attitude is more positive, we will be able to start using this immense source of energy much sooner.

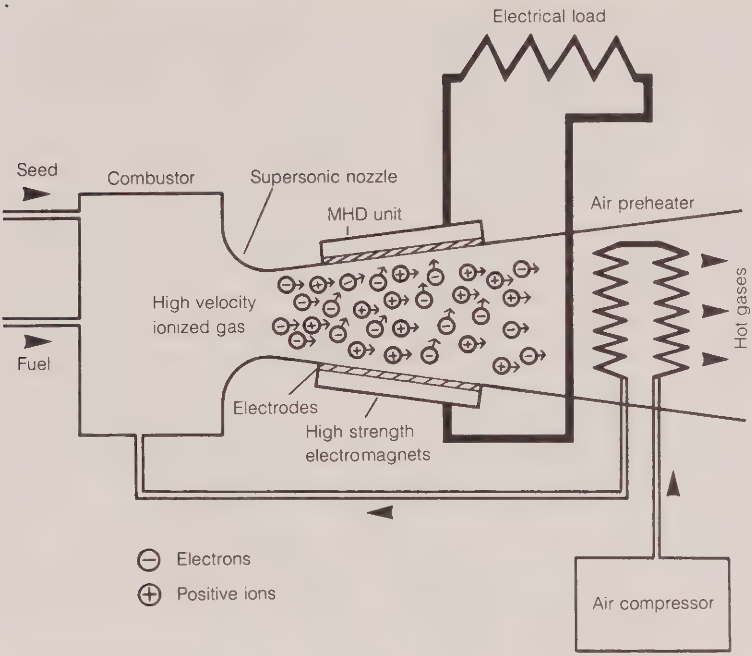

Figure 12. Diagram of a magnetohydrodynamic generator, in which a stream of hot, ionized gas is passed through a magnetic field to produce electricity. (Source: Stanley J. Townsend)

Methods of Converting Energy

Something should be said about the means of converting energy from the primary source to a form that is easier to use. Most primary sources used today have their chemical energy converted into heat energy or thermal energy, then into mechanical energy, and perhaps into electrical energy. There are two general categories of machinery for converting energy – positive displacement machinery and turbo-machinery. Positive displacement machinery includes the common piston in a cylinder, as used in spark-ignition and compression-ignition engines, as well as in the Wankel engine. Turbo-machinery includes the steam turbine, in which steam from a steam generator expands to produce work; it includes the gas turbine, in which air is the working fluid and is heated by the addition of a fuel. All of these devices work on

thermodynamic principles and all obey the laws of thermodynamics, because energy in the form of heat is involved. There are also other kinds of heat engines, such as thermo-electric converters and thermionic converters, which are, of course, governed by the laws of thermodynamics.

There are also energy converters that are not heat engines. No energy is released as heat, so the laws of thermodynamics, and particularly the one that limits the amount of energy that can be converted in a process, do not apply. The fuel cell is one such device, and the hydraulic turbine is another. They, of course, are limited by the law that states that energy can be neither created nor destroyed, which means that you cannot get out more than you put in.

Magnetohydrodynamics involves passing a conductor through a magnetic field to produce electricity. The conductor is a stream of hot, ionized gas; mechanical energy in the form of kinetic energy is converted into electrical energy. It has been proposed that magnetohydrodynamics should be the first stage of electric power production, the very hot gases passing from the generator to the boilers to give up more heat in a conventional steam generation unit. This is shown in Figure 12.

Another concept that is receiving much attention is the "hydrogen economy", in which hydrogen is the basic fuel. Hydrogen does not occur naturally, so it must be produced from a more primary energy source. Hydrogen is a means of storing energy in a portable and readily available form, and it can produce high temperatures. It is a likely substitute for fuels used in transportation, but it will undoubtedly encounter competition from fuels produced from biomass.

Long-term Possibilities of New Technologies

The renewable energy sources that appear to have the greatest application in Ontario are wind, waves, biomass, ocean temperature gradient, direct solar energy, and, of course, water. The direct solar energy includes solar thermal, solar electric, and solar heating and cooling. Fusion power is a long-term possibility, maybe for the 21st century, but the other renewable sources that have been described are not strong possibilities in Ontario.

Magnetohydrodynamics may improve the efficiency of thermal power plants, perhaps raising their thermal efficiency from 40 per cent to 60 per cent. However, the primary sources of energy for such plants are finite – fossil fuels and nuclear fuels. Coal gasification or liquefaction, and enhanced oil and gas recovery, may allow our fossil-fuel resources to last a bit longer, but they are still finite sources. Breeder reactors may make the conversion of nuclear fuels by fissioning more efficient, but uranium is finite and so is thorium, although thorium is believed to exist in greater quantities than uranium.

Conservation is of extreme importance. In fact, conservation will allow us to become much more sophisticated in our use of energy. It is the key that will open the door on renewable energy resources. Conservation can extend the life of our finite resources, and conservation can reduce the level of pollutants of all kinds, simply because it reduces the demand and therefore the output from the offending plants.

It is difficult to predict commercial dates or costs for these new technologies. Already solar houses are springing up, but the federal and Ontario governments are doing very little in these areas. There is no well-organized, national research and development program for renewable energy resources in Canada. The federal government budgeted half a million dollars in 1976 for demonstrations, but this was coast-to-coast, so that no one area or activity would get much money. Several solar projects were sponsored by the Ministry of State for Urban Affairs for Habitat, but there seemed to be no plan.

It is worth while to look at solar energy research activities in other countries.[23] The United States is making the most intensive effort of any country. They are spending millions of dollars each year, and doubling the budget for solar energy every year. The Japanese are planning to spend 930 billion yen ($3 billion) between 1974 and the year 2000 on solar energy. The implementation plan for the Japanese project "Sunshine" for the first stage, up to 1980, includes the development of: a solar thermal system of about 1 MW; photovoltaic systems cheaper by a factor of 100 than those currently available; thermo-electric conversion systems; solar cooling and heating systems for buildings and hot water supply systems; and practical uses for solar furnaces. The project also calls for meteorological studies on energy availability.

France spent 79.2 million francs ($30 million) in 1975 on research and development on new energy sources. Of this amount, 28.2 million francs ($11 million) was spent on solar energy. A study is

A vertical axis wind generator operated by Quebec Hydro on Magdalen Island. This turbine develops 200 kW from a rotor with a horizontal diameter of 80 feet. The total height of the installation is 150 feet. (Source: Dominion Aluminum Fabricating Limited)

under way on a 25 MW solar thermal power station to be built by 1981. The thermal use of solar energy in housing has been assigned to Electricité de France, the French electrical utility similar to Ontario Hydro. Ten houses have been built, funded by the

Ministry for the Quality of Life. The French methane production program, which lies outside the solar energy program, received one million francs ($300 thousand) in 1975, with the long-term aim of recovering 20 per cent of the energy in urban wastes and 30 per cent of the energy from animal wastes.

The Federal Republic of Germany is subsidizing energy research projects with one billion deutschmarks ($420 million) to cover the next four years, of which 16 million DM ($7 million) are for solar energy projects. The emphasis is on industrial involvement. Most projects are subsidized at 50 per cent by the government, industry providing the other half. The largest utility company in Germany is participating in nearly all of the solar projects.

Many other countries have shown interest in solar energy – Denmark, Holland, and Ireland, in particular. The United Kingdom has supported some activity at universities, but has been very conservative in committing funds. A recent report in the U.K. suggested that the solar water-heating market will be 100,000 units by 1985, with an approximate market value of £200 million ($300 million).

In the U.S., ERDA issued a two-volume publication, *Creating Energy Choices for the Future*, in June 1975. Volume 1 is called *The Plan* and Volume 2, *Program Implementation.* The U.S. program has had input from the political processes through Congress, from technical experts in various government agencies and laboratories, and from industry. The ERDA volumes, with others such as *Solar Energy as a National Energy Resource*, issued in December 1972, make rough predictions possible for the application of solar energy in Ontario.

Wind-energy conversion systems of 10 MW size will be demonstrated in the U.S. by 1981, and systems of 100 MW will be built by 1984. The wind-profile maps do not show any particular advantage for the U.S. over Ontario in considering energy from the wind. The *Ontario Wind Report* of November 1975 was a modest effort, but it did represent a forward step in providing a technological perspective on possible applications for Ontario.

The U.S. expects to have the potential by 1985 to produce considerable energy from agricultural and forest residues. A 1976 Ontario study on the utilization of forest residues pointed the way towards the utilization of biomass. The U.S. program will have three large-scale demonstration projects – one from each of the major alternative energy farming systems: field crops, wood crops, and marine biomass. All three could have a big impact in Ontario.

Ocean temperature gradient may not have any application in

Ontario, but there seems to be some potential for it in the cold waters of Lake Superior and Georgian Bay. The cold waters at depth and the surface temperature or the air temperature might perhaps be the basis for a practical thermodynamic cycle.

Solar heating and cooling is expected to contribute between 0.2 and 0.6 per cent of the total U.S. demand by 1985. If each house in Ontario obtained 50 per cent of its heating needs from solar energy, this would be a significant amount of energy. Solar thermal and solar electric will be practically demonstrated in the U.S. within five years – and more interest is likely to be shown in Ontario once it has been seen working on as large a scale as 10 MW to 100 MW.

None of the alternative energy sources has any serious environmental or health consequences. The towers to support windmills would not be any more unsightly than hydro towers. The high intensity light on a power tower would not be as intensive as the sun itself. There would be no pollutants, such as smoke, radioactive particles, or microscopic particulates.

The costs are difficult to assess. Everything built to date has been experimental. Regardless of the cost now, as time goes on and the costs of other forms of energy increase, the renewable sources will become more competitive, and they may be the only ones available, at any price, eventually.

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Nuclear Energy in Our Time

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The physical processes involved in the releasing of nuclear energy from the atomic nucleus are quite different from any that take place in more conventional electrical power steam plants, and the purpose of this paper is to explain them – to show how electricity is made from uranium. Also, we will examine the advantages of nuclear energy, as perceived by its proponents, as well as some of the objections that have been raised against it by those who would prefer to see alternative energy sources developed.

The nuclear technology will be explained in simple terms and compared with other energy technologies. It is no new or unproven technology proposed for the future, but a real and actual one, already in operation in the form of Canadian-designed CANDU plants. These are sufficiently well established in design, performance, and safety to be considered a full-scale demonstration of a proven, working technology. Such is not the case with some of the renewable energy sources that are proposed as alternatives. The means to harness solar energy or windpower in a way that would provide any significant part of Ontario's energy needs at acceptable costs are not available and may not be for many years.

The nuclear power generating system that is explained and discussed here is the one that is proposed as a basis for the expansion of generating equipment for Ontario for the next 10 or 20 years – the CANDU reactor like those used for the Pickering and Bruce plants, with minor modifications. Other reactor systems are compared briefly with CANDU for differences in design that have to do with safety. But the safety issues associated with nuclear reactors that have been developed in other countries are not

considered in any detail; it is the CANDU system and likely future versions of it that we are mainly concerned with.

The development of nuclear power inevitably entails some risk, both to workers and to the public, of over-exposure to radiation. This risk can arise from the operation of the reactors or from the processing of uranium and its handling before and after its use as fuel in reactors.

Exposure to nuclear radiation did not begin with the advent of nuclear power. Man has always lived in an environment containing natural radiation, and Canadians today are exposed daily to ionizing radiation, both natural and man-made. The contribution of nuclear power to ambient, or background, radiation has, up to now, been negligible compared with the contribution from natural sources and, particularly, from medical X-ray procedures.

However, it remains a matter of concern to some people that any large growth in the nuclear industry might endanger not only workers in the industry, who are closely scrutinized for possible over-exposure to radiation, but also the citizens of Ontario at large.

Origins of Nuclear Energy

A remarkable feature of nuclear power plants is the relatively small quantity, or mass, of nuclear fuel they require. In the Pickering nuclear generating station, for example, only a few hundred pounds of fuel in the form of fuel bundles have to be loaded into the reactors each day, whereas in the Lakeview fossil-fuelled plant, operating at a similar level of power output, thousands of tons of coal are daily reduced to ashes and stack gases.

Rudimentary ideas about the releasing of enormous quantities of energy from small quantities of matter predate the discovery of the atomic nucleus. As early as 1905, when Albert Einstein's mass-energy relationship, $E=mc^2$, was published as a part of his special theory of relativity, the remote possibility of releasing energy by rearranging the basic structure of matter was recognized, taking the mass-energy relationship into consideration along with certain anomalies in the distribution of atomic weights among the elements. By 1925, several years after Ernest Rutherford discovered the atomic nucleus and elementary nuclear reactions, it became clear in the light of Francis Aston's detailed atomic mass measurements of some 50 elements that the release of nuclear

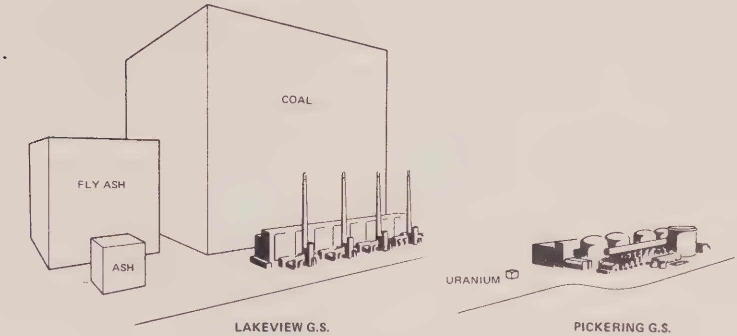

Figure 1. Comparison of the lifetime fuel requirements of the Lakeview and Pickering generating stations. Waste produced by the Lakeview station is also shown. (Source: Atomic Energy of Canada Limited)

energy on a large scale would be possible if a suitable nuclear reaction could be discovered.

The right reaction would be one that involved the transformation of nuclear matter from one of the states in which it normally occurs, among the atoms of the Earth's crust, into a more tightly bound, less massive state containing less internal energy; nuclear energy would be released in such a transformation in proportion to the change in mass. The actual reaction would also have to be self-sustaining; in other words, the outcome would have to contribute to the conditions needed to produce further, similar reactions.

One of the earliest applications of the concept of a self-sustaining nuclear reaction was its use by Hans Bethe during the 1930s to show that the energy produced in the sun and other stars is due primarily to nuclear reactions, in which nuclei of the lighter elements collide with each other at sufficient speed to fuse into more tightly bound nuclei, releasing heat-producing radiation in the process. The rate at which nuclear reactions are taking place is sustained by the fact that the temperature of a star, and hence the vigorous thermal motion of the nuclei, is maintained by energy that was released in earlier collisions that resulted in fusion reactions. The entire process is commonly referred to as the thermonuclear fusion process, and it explains how the stars are able to go on releasing enormous quantities of energy throughout their long lifetimes.

It should also be pointed out that it is the thermonuclear process that gives rise to the particular range of chemical elements and their various isotopes that we find in the matter making up the planet Earth. This matter originally belonged to a star – probably our own sun – before some cosmic event thousands of millions of years ago caused it to separate from the star and consolidate into a mass resembling our planet. The particular range of atomic species to be found in the Earth's crust was therefore a product of the parent star's earlier thermonuclear processes. This process of creating a range of nuclear species through the successive fusing together of light nuclear species is called nucleogenesis, and an appreciation of its role in establishing the Earth's chemical and nuclear composition is necessary for an understanding of man-made devices to release nuclear energy.

Some vital points follow readily from the concept of stellar nucleogenesis:

1. We live in a universe in which, with a few exceptions like the planet Earth, all matter is in a state of nuclear turmoil, either in stars at various stages of their life-cycles or as interstellar matter moving at such speeds that much of it is actually ionizing radiation.
2. The Earth itself, when first severed from its star, was violently radioactive, but changes in the atoms ceased with their removal from the stellar conditions. Most of its radioactive atoms have since decayed into the stable atoms that now constitute the chemicals making up the Earth.
3. The Earth's present natural radioactivity is composed of radioactive atoms such as uranium-238, thorium-232, and traces of plutonium-244, which have half-lives of the same order as the age of the Earth and have existed since their stellar beginning, and of radioactive atoms that have shorter half-lives but are continuously being created, either through the decay of their long-lived parents or in nuclear reactions produced by cosmic rays that have penetrated the Earth's atmosphere. Examples of naturally occurring radioactive atoms with shorter half-lives are the decay products of uranium-238 (radium-226 and radon-222), and carbon-14 and hydrogen-3 (tritium), which are produced by cosmic-ray bombardment of the atmosphere. ("Half-life" refers to the time required for half of the atoms of a radioactive substance to lose their radioactivity.)
4. The radiological component of the Earth's natural environment, that is, the ionizing radiation that strikes the cells of living organisms inhabiting the Earth, is due to a combination of the radiation emitted in the radioactive decay of the isotopes described in (3) and cosmic-ray showers created in the atmosphere by the bombardment of cosmic particles.

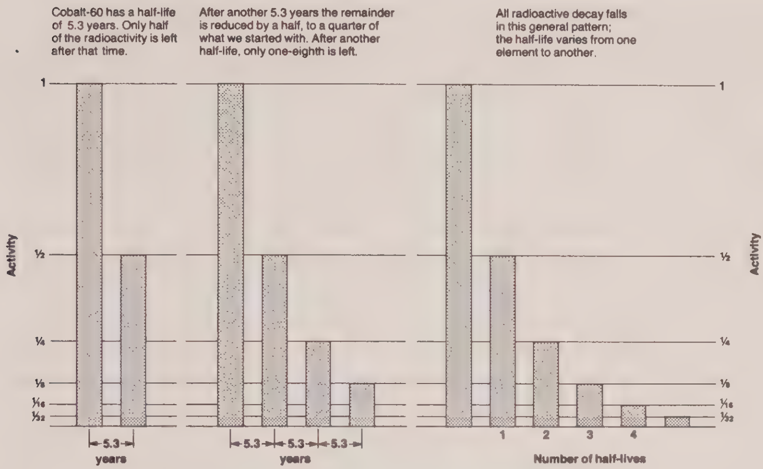

Figure 2. The concept of half-life is represented here in a bar chart for the artificially produced cobalt-60 isotope and for radioactive atoms generally. Uranium-238 has a half-life of 4,500,000,000 years, which is also the estimated age of the Earth. Plutonium-239 has a half-life of 24,400 years. (Source: Atomic Energy of Canada Limited)

In summary, a consideration of the origin of the Earth's material indicates that the Earth, since its formation as a separate celestial body, has become a place of little radiation in comparison with the rest of the universe. The invention of ingenious devices and systems to release residual energy by transforming still further some of the Earth's endowment of radioactive atoms represents, on a very minor scale, the rekindling of nuclear fires that played an important role in the early formation of this planet. In exploiting nuclear energy in this way, we must be careful to ensure that the radiological environment will not be appreciably altered.

We return now to the question of which energy-producing nuclear reactions may be feasible on a large scale as the operating principle in nuclear power reactors. We have already indicated that a fusion reaction is readily sustained by thermonuclear processes in a star, in which the massiveness of the star permits the very hot gas (plasma) to be contained by gravitational forces. On Earth, the atomic nuclei that are most suitable as fusion fuel are deuterium and tritium, both isotopes of hydrogen. Deuterium occurs naturally in small amounts with ordinary hydrogen, but tritium must be bred by allowing neutrons, as a by-product of the fusion reactions, to be captured in lithium-6.

To date, fusion reactions on Earth have been "sustained" only in H-bombs, in which a full charge of fuel is virtually consumed in fusion reactions within ten billionths of a second. The energy released in this manner is considered unmanageable for purposes of power generation, and intensive research has been under way since the mid 1950s (mainly in the U.K., the U.S.A., and the U.S.S.R.) with the objective of releasing fusion energy more slowly and more or less continuously.

In spite of recent increases in budgets for fusion research, nuclear fusion power plants are not expected to be in service until well into the next century, even if their scientific feasibility is demonstrated within the next decade. Fusion power plants, if they eventually become available, will represent yet another alternative source of energy, and the anticipated advantages are many.

The early measurements of atomic mass showed that the transformation of heavy atoms, such as those of uranium, into lighter atoms would release nuclear energy. However, since heavy nuclei possess a large positive charge that repels other charged particles, the chances of actually transforming heavy atoms through what we now call the fission process seemed remote. The discovery of the neutron in 1933 by James Chadwick opened up the possibility of a fission process, because the neutron, being essentially a nuclear particle with no charge, requires no minimum energy to penetrate the nucleus and disrupt its stability. Artificial neutron-induced fission was achieved in 1938 by Otto Hahn and Fritz Strassman in experiments involving the irradiation of uranium with neutrons. Subsequent research showed that not only a large amount of energy but also two and one-half neutrons were released in the typical fission event. Thus it was shown that energy could be released at apparently unlimited rates by a succession of fission events sustained by a "neutron chain reaction", in which the neutrons produced in each fission event would induce further fission events.

Further experiments showed that the minor uranium isotope U-235, with a relative abundance of only 0.7 per cent in natural uranium, was the only fissile material in uranium and that, in the presence of non-fissile material such as U-238, only slow-moving neutrons would produce enough fission events to sustain the chain reaction. (Fissile describes materials that are necessary to sustain a neutron chain reaction.)

It is as a direct result of these findings that all commercial power reactors in operation today use a moderator such as graphite,

heavy water, or ordinary water to slow the fast neutrons that were born in fission down to energies about 100 million times lower. The presence of a moderator, distributed with the uranium throughout the core of the reactor, is essential in CANDU reactors, which are fuelled with natural uranium fuel, as well as in light-water reactors (LWRs), for which the U-235 content of the fuel must be increased from the natural level of 0.7 per cent to about 3 per cent. (The CANDU is a Canadian-designed reactor whose name is derived from its description – Canadian deuterium uranium.) CANDU and LWR reactors are often referred to as "thermal" reactors because the neutrons they produce are at low, or what are called thermal, energies.

One further concept, that of fuel "breeding", is essential for a full appreciation of how energy is derived from the fission process. Breeding consists of using some of the spare neutrons (theoretically, only slightly more than one neutron of the 2.5 that are produced in a fission event is required to sustain a chain reaction) that are produced in a reactor to convert fertile atoms, such as U-238, into fissile material, such as plutonium-239. This process goes on of its own accord in a thermal reactor because of the presence of large amounts of U-238. Consequently, by the time a

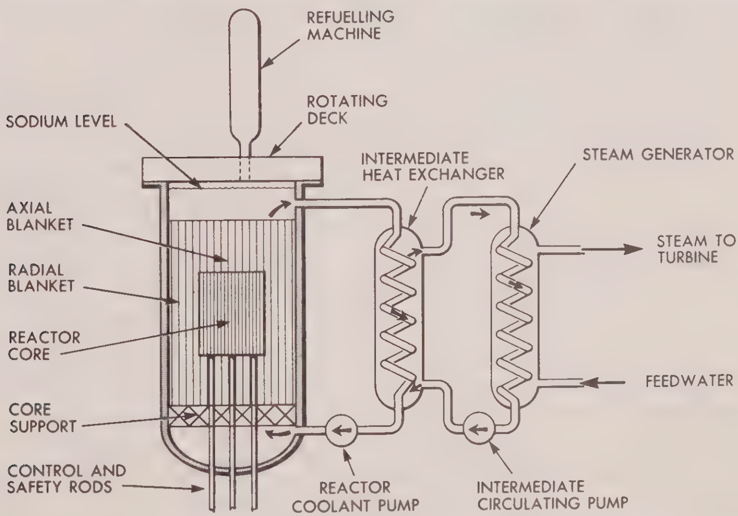

Figure 3. Schematic diagram of a liquid sodium cooled fast breeder reactor, designed to sustain a chain reaction with fast neutrons. Surplus neutrons from fission are absorbed by fertile uranium-238 (the blanket) and converted into additional fissile material. Such reactors are not yet operating commercially. (Source: Atomic Energy of Canada Limited)

fuel bundle is removed from a CANDU reactor, as much energy has been derived through the fissioning of "bred" plutonium as from the original U-235.

Much larger amounts of fissile fuel can be bred in reactors designed expressly for the purpose. Although such reactors are not yet in commercial operation, the so-called "fast-breeder" reactor, which operates on concentrated fissile material and without a moderator, is expected to increase the quantity of energy that can be derived from a ton of mined uranium to about 50 times that presently obtained by the use of thermal reactors. The CANDU reactor was not intended to perform as a breeder-reactor, but it is conceivable that its further development may result in raising its output of energy by a factor of 10 to 20. Such a refinement of the CANDU reactor, referred to as a thermal "near-breeder" reactor, would operate on a thorium fuel cycle in which fissile U-233 would be bred from thorium, which is as abundant in the Earth's crust as uranium.

Thus, the concept of fuel breeding has the potential to extend the energy output from nuclear fuel reserves by a factor of 10 to 50.

Energy from Nuclear Fission

At the root of what happens inside a present-day nuclear reactor is the phenomenon of nuclear fission. It is a unique process in many ways, and one whose discovery opened up large new areas of research for scientists and engineers, because of its novel and radical aspects.

The fission process differs in several ways from ordinary physical and chemical processes. It is accompanied by a very large output of energy; its products, the so-called "fission products", are unusual; and it regenerates neutrons, which are necessary not only to initiate the fission process, by causing the first fission event, but also to perpetuate it – in much the same way that earned money, reinvested in a business, enables it to flourish.

Natural uranium consists mainly of two different forms of the element – U-238 atoms and U-235 atoms, in the ratio of 140 to one. Only the less abundant U-235 atoms are fissile – capable of "splitting", or undergoing fission, when they absorb low-energy neutrons. U-238 atoms can absorb neutrons when struck by them, but instead of splitting when this occurs they increase their mass

and turn into plutonium-239 – which, like U-235, is fissile. Because U-238 can breed fissile plutonium, it may be said to be "fertile".

What happens within the nucleus of a U-235 atom when it first receives a blow from, and then absorbs, a low-energy, or slow-moving, neutron may be compared with what sometimes happens to a drop of water hanging from the spout of a tap. If it is disturbed by vibration, the spherical drop may lengthen into a dumbbell shape for a moment and then resume its former round shape. If the vibration is severe enough, the drop may split into two droplets, one of which will fall. Similarly, with very little excitation and merely by taking a low-energy neutron into its nucleus, a U-235 atom can split into two parts. When this occurs there is a great burst of energy that not only ejects two or three neutrons but also charges all of the fragments of the original atom with kinetic energy.

It is the creation of two or three free-moving neutrons by each fission event that leads to the possibility of a chain reaction in which the number of neutrons increases rapidly through a succession of fission events, and the number of U-235 atoms undergoing fission also increases rapidly.

The neutrons produced in each fission are released with far too much energy to be able to sustain further fissions in the usual concentrations of fissile atoms found in nuclear fuels. They must be slowed down before they can induce further fissions, so the key to a self-sustaining fission process is an efficient arrangement for reducing the neutrons' energy. This can be done by giving them a material to collide into, to which they will transmit a good part of their energy. Such a material is called a "moderator", and it must have atoms similar in mass to neutrons. Hydrogen, deuterium, beryllium, and carbon atoms have all been used as moderators. The moderator is heated up by absorbing the neutrons' excess energy but is not itself radically altered.

The main fragments that remain after the splitting of a U-235 atom (the "fission products", as they are called) carry away most of the fission energy and get rid of it as heat by colliding with other uranium atoms in the solid rod of uranium oxide that is the source of the fissioning atoms. The fission products, having masses typically equal to about half that of the unsplit uranium atom, range from zinc (one of the lightest) to bromine, iodine, cesium, and some other rare elements.

Because of the way they are formed, the fission products are inherently radioactive and some of them change rapidly into other

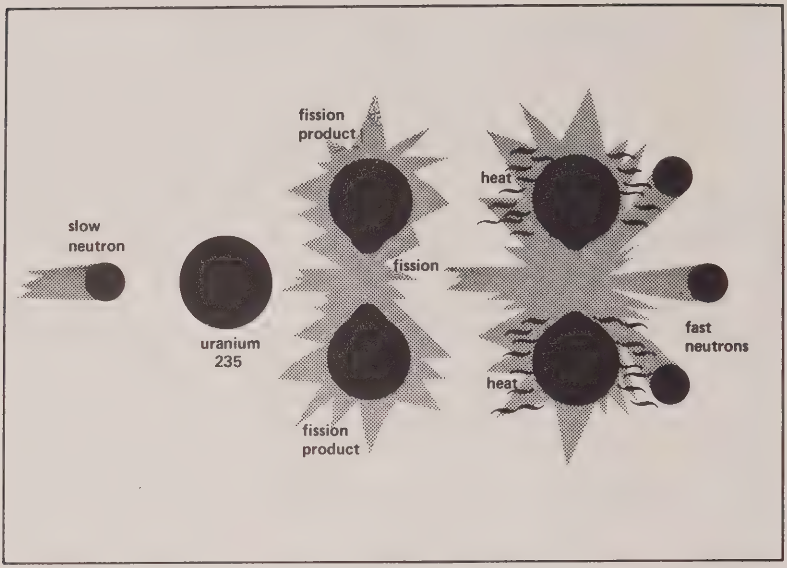

Figure 4. A slow neutron strikes the nucleus of a uranium-235 atom and splits (fissions) it into fission products, which release heat as they fly apart. (Source: Atomic Energy of Canada Limited)

radioactive substances. Some are gaseous in their normal state; others are solids. In small concentrations, the fission products are randomly dispersed among the uranium atoms and cause only a negligible change in the properties of the uranium. The significant thing about them is their radioactive nature. Gram for gram, they have a radiation intensity many billion times greater than the original uranium. Not only that, but they will lose this intense radioactivity only over a period of thousands of years of gradual radioactive decay.

Neutrons are also absorbed by U-238 atoms to form plutonium, so there is, in effect, a competition for neutrons between fissile atoms and non-fissile atoms. If the fission process is to be encouraged, engineers have to provide the best possible physical arrangements of layers of uranium (or fissile plutonium) and layers of a suitable moderator suitably spaced so that a good number of the neutrons can cause fission events before they are lost, or absorbed in other materials. Again, the analogy of business is helpful: in a well-planned operation, the best possible use is made of dollars available for investment, so as to produce higher profits with minimal wastage.

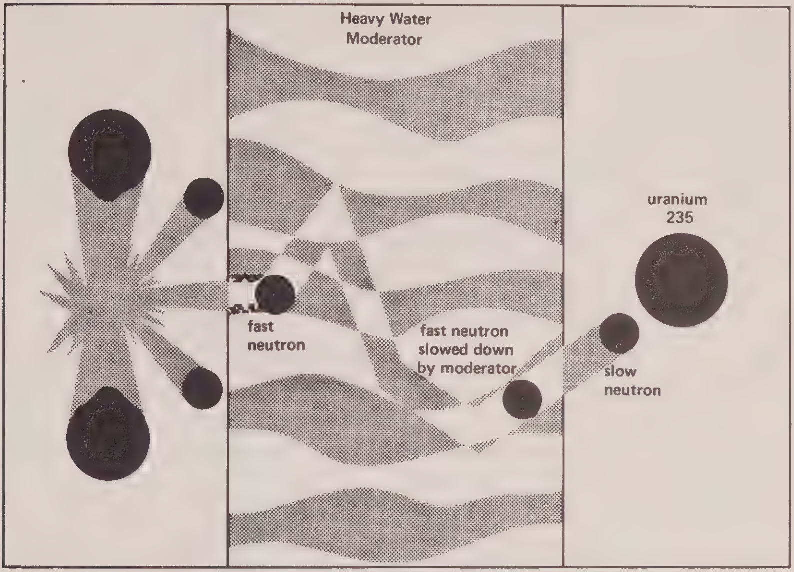

Figure 5. Fast neutrons given off in fissioning are slowed down (their speed is moderated) as they bounce against the nuclei of heavy-water atoms. The slow neutrons create a chain reaction by splitting additional U-235 atoms (see Figure 4). (Source: Atomic Energy of Canada Limited)

Atoms in addition to U-235 and plutonium-239 that are capable of fissioning are U-233, which can be made from thorium in the same way that plutonium-239 can be made from U-238, and the heavier isotopes of plutonium. There is an even greater range of materials that can be fissioned with "fast" neutrons, and some of these have been used in experimental nuclear reactor systems. But nuclear power development has been based so far on the use of slow neutrons, and it will probably continue to be for the rest of this century. For this reason, most of what follows concerns fission systems using slow neutrons, and likely future modifications of such systems.

Nuclear Fission – Some Technological Considerations

Nuclear energy is derived from changes deep in the interior of selected heavy atoms of uranium and plutonium. These particular

atoms are capable of undergoing fission, or a split in their nuclei, when they are struck by neutrons. The process releases very large quantities of energy, which results in the production of heat within the uranium material, and this heat can be carried away and used to produce steam. After that, the process for generating electricity is the same as with fossil fuels.

The energy-producing fission process and the heating occur randomly within a nuclear reactor in solid rods of uranium oxide, and they involve only a small proportion of all the atoms in each rod. In natural uranium, as we have seen, fewer than one per cent of all uranium atoms are capable of low-energy fission, so that even after a rod has been releasing fission energy for many months only a small part of the uranium will have been fissioned.

The nuclear heat-producing process is, therefore, very much simpler than the fossil-fuel process in which the fuel must be vapourized and dispersed during combustion, requiring a plant designed to inject fuel and disperse the products continuously. In nuclear fission the energy is produced and can be dissipated continuously from a solid fuel. The changes that take place in the fuel are not readily visible but they are significant. Particularly important is the accumulation of intensely radioactive fission products, some of which are inert gases. Some heavy elements are also produced by the conversion of uranium atoms in a process that consumes neutrons in competition with fission. These are known as "actinide elements", and the most important of them, in the used nuclear fuel, are isotopes of plutonium.

There are three main consequences, then, of the sustained release of energy by nuclear fission: a large amount of heat is produced, and it must be extracted for use as the source of power; neutrons are produced which escape to the surrounding uranium fuel and can propagate the fission process; and radioactive by-products are left behind as "nuclear ash", or waste, which has little potential value in nuclear energy systems (except for the plutonium it contains) and must be disposed of and handled carefully for many years. The radioactive waste products that have accumulated by the end of the useful life of a typical rod of uranium fuel often weigh less than one per cent of the original rod. However, any release of even small quantities of them into the reactor system or into the environment is hazardous, and measures must be taken to ensure that such releases cannot occur.

Heat from fission is harnessed to produce steam, which is used to generate electricity, just as in a fossil-fuelled power plant. So

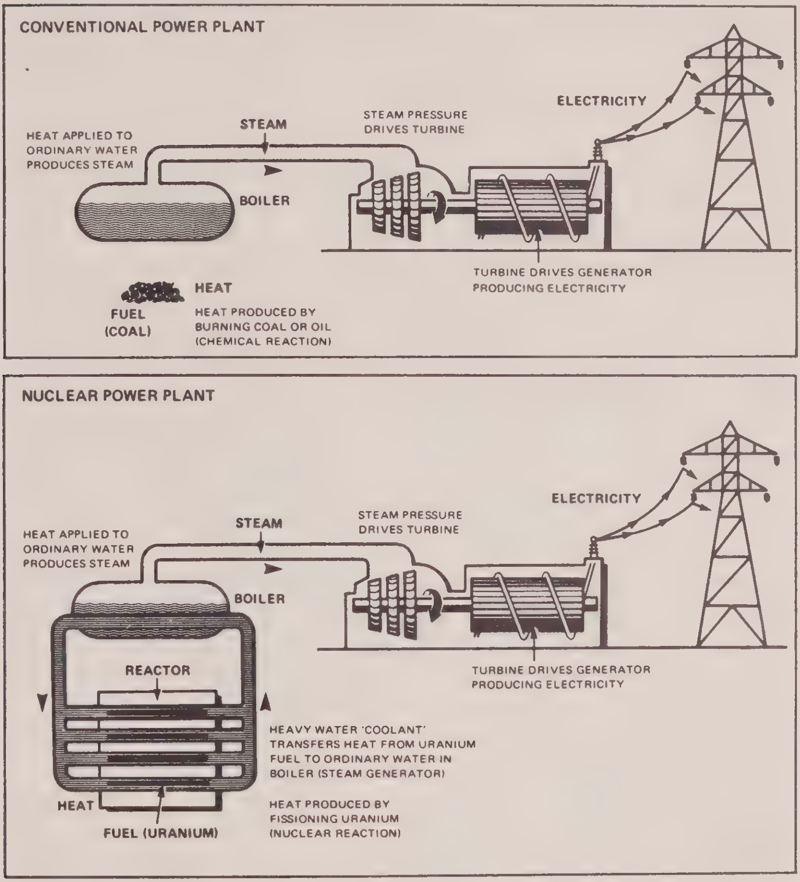

Figure 6. Comparison between a conventional and a nuclear power plant. The heat source in the latter is a nuclear reactor, instead of a furnace burning coal, oil, or gas. (Source: Atomic Energy of Canada Limited)

both types of plant have many of the same components. The nuclear plant is continuously supplied with solid fuel. Heat produced in the fuel is collected and carried away to produce steam which operates an electricity-generating turbine. Waste products, or ash, are produced by the burned part of the fuel, and in due course the fuel with its accumulated ash must be removed and fresh fuel inserted.

However, fossil-fuelled plants differ significantly in some ways from nuclear plants. In them, fuel is atomized and dispersed during combustion, and the resulting heat is carried from the

combustion chambers by the flue gases, which take with them some particulate matter and pollutants that must be trapped. Capturing as much as possible of the heat in the flue gases and using it efficiently to produce steam require careful engineering. The most efficient modern fossil-fuelled plants can convert 35 to 40 per cent of the heat generated into electric power. Nuclear plants are a little less efficient, and one of the reasons for this is their lower operating temperatures. Temperatures of about 550°C are reached in nuclear plants, compared with temperatures of about 2,000°C in fossil-fuelled plants. In nuclear plants, to keep the temperature of the fuel below the melting-point, it is necessary to maintain a steady flow of liquid coolant over the solid fuel. Some of the concern about the safety of nuclear reactors is focused on the consequences of any interruption to the flow of coolant; the result would be a rapid increase in the temperature of the uranium.

Another point of comparison is the time required to start up or shut down a plant; the time is much shorter for nuclear plants, but this can be a disadvantage since, once it has been activated, a nuclear plant can accelerate very quickly to high power levels – even to levels that could damage the fuel or the structure of the reactor. As a precaution, safety devices must at all times be ready to limit the rate of increase of the power. The rapid rise referred to is possible because all of the fuel needed to power the system for several months is normally available in a nuclear plant. In a fossil-fuelled plant, however, fuel has to be supplied continuously in dispersed form and only enough for a few minutes is supplied to the combustion chamber at any time. Even if the control devices were not functioning, the very lack of fuel would rapidly eliminate any possibility of a power surge in a fossil-fuelled plant.

When comparing the nuclear and conventional power-generating technologies, it is helpful to realize that heat produced at the high temperatures characteristic of fossil-fuelled plants can be very efficiently converted through steam into electricity. The use of fission heat at lower temperatures, as in the Canadian water-cooled reactors, is inherently less efficient.

The concept of "net energy" offers another way of comparing the two technologies. The total energy consumed in the construction of a plant is plotted against the useful energy output of that plant. A nuclear plant constructed to the highest standards of safety must operate for 12-15 months to produce enough electricity to equal the electricity that went into its materials and construction. In the operation of a nuclear plant, however, the energy consumed

is mainly electricity and it represents only a very small part of the uranium consumed, so that no other energy resource is being depleted during the generation of electricity.

The Nature of the Radiation Risk

Nuclear radiation may be defined as the ionizing radiation that is emitted as excess energy as a result of processes of change in the atomic nucleus. This radiation may be emitted either right at the time of the change in the atomic nucleus or during the subsequent period of nuclear decay of the radioactive atoms. Nuclear radiation is not of a single type or form. It consists of streams of high-energy particles called alpha particles, beta particles, and neutrons, and these are often accompanied by high-energy electromagnetic radiation called gamma rays. Gamma rays are not unlike other forms of electromagnetic energy (solar, thermal, microwave, laser, X-ray) but they are of much higher energy per smallest unit, or quantum, and are more penetrating. Human hazards associated with exposure to radiation are not all due to nuclear radiation. However, nuclear radiation can occur at a higher intensity than other forms of radiation, and radioactive chemical elements, each

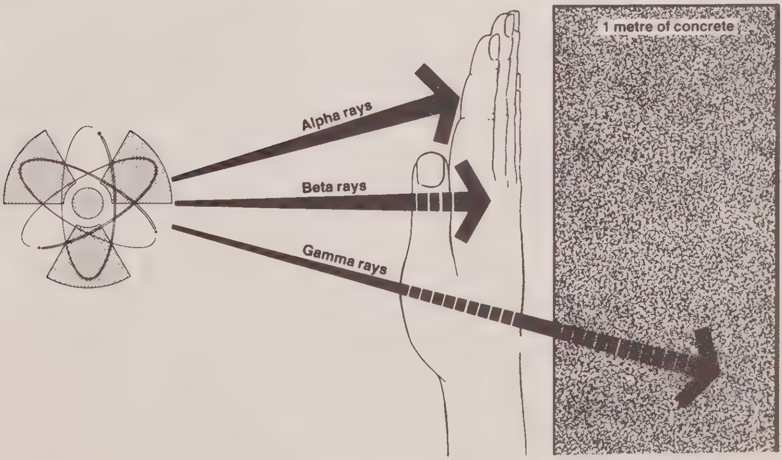

Figure 7. The penetrating power of radiations. Alpha rays will just penetrate the surface of human skin. Beta rays will penetrate one to two centimetres of tissue. (Source: Atomic Energy of Canada Limited)

with its own specific behaviour in the environment, present a unique human hazard.

Alpha rays, beta rays, gamma rays, and neutrons all have quite different physical properties and can have different biological effects on living matter they encounter. Most of these effects are of little consequence: the organisms affected can quickly repair or replace any cells that are damaged. But exposure to nuclear radiation also has some rare side-effects involving cancer and potential genetic defects. The manner in which a dose of radiation is received by an organism can be important. Gamma radiation, by its nature, causes a diffuse absorption scattered throughout the organism. Alpha and beta radiations can deliver their energy in a more concentrated form, affecting only a small area of the organism. The potential for causing some irreversible cell damage or an incipient malignancy can therefore be quite different between the different forms of radiation, depending on how the organism is exposed and where the energy is deposited.

Research has shown that of all organisms man is among the most vulnerable to radiation damage. In assessing the risk, it is necessary to distinguish between the different ways in which radiation, either natural or man-made, can reach the human body. Background radiation from a fixed source in a working or living environment can irradiate a human body from the outside; the closer a person moves to a source of radiation, or the longer the person remains in its vicinity, the greater is the dose delivered to the body. The radiation dose from such an external source can be controlled by limiting the intensity of the source, limiting the duration of exposure, increasing the distance from the source, or installing shielding material capable of absorbing some or most of the radiation before it can reach the body.

The strength of a nuclear radiation source is measured by a unit called the curie, which is based on the rate at which disintegration is occuring in the atomic nuclei within a mass of radioactive material. Some radioactive materials lose their radioactivity in a matter of seconds but in that short period of time emit enormous numbers of curies per gram. Others have very long "half-lives". The disintegrating atomic nuclei of natural uranium, for example, emit only a few "disintegrations" per gram per second, and it takes about a ton of natural uranium to emit enough disintegrations per second to make up one curie.

In addition to causing "external whole body radiation exposure" by their presence in the environment, radioactive atoms, or

particles, if allowed to escape into the air or the water, may become incorporated into living matter. They may be inhaled or ingested and so become a source of internal radiation exposure. The extent and gravity of such internal exposure will depend on various factors: how long the radioactive atoms stay in the body, the site at which they become deposited, the duration of the half-life of the atoms, and their ability to deliver radiation to the vital organs and tissues. Radioiodine, for example, is readily absorbed and tends to concentrate itself in the thyroid. Strontium and plutonium deposit themselves in bone. Uranium is retained only for a few days and is then excreted. These factors must be taken into account when the risks are being calculated.

It is clear that the possibility of radioactivity leaking into the environment from uranium refining and processing plants or from nuclear reactors must be considered in any assessment of the possible impact of nuclear technology on the citizens of Ontario. It is important to note the various pathways by which radioactive emissions can reach man and cause external and internal exposure to radiation. The fate of radioactive atoms in the environment will not be dealt with in this paper. However, we will go on to consider the mechanisms by which nuclear reactors and the facilities for handling and storing nuclear fuel and radioactive waste can emit radioactive atoms.

Safety Aspects of Nuclear Power Systems

There are several important safety aspects to be considered in a large-scale nuclear power system. First, there is a build-up of immense quantities of radioactive products during the normal operation of the reactors; the bulk of the products is sealed into the fuel bundles, but smaller amounts of them are produced in the heavy-water coolant, in the gaseous effluents, and in the structural components of the system. Then there is the risk of accidental releases of radioactivity from the used (i.e., irradiated) nuclear fuel, either when it is being chemically reprocessed to reclaim the plutonium or while it is in long-term storage. Finally, as recent experiences of uranium miners have shown, significant risks are associated with the mining and refining of uranium ores and their fabrication into fuel for nuclear reactors.

A fuel bundle for the Pickering reactor. Each bundle weighs approximately 24 kg and produces the energy equivalent of 450 tons of coal during the 18 months it stays in the reactor. (Source: Atomic Energy of Canada Limited)

Reactor systems are designed to keep radioactive by-products contained within the system, even if there are failures, cracks, or leaks in the components. CANDU reactors are designed to keep radioactive atoms contained within them, even in the event of accidents. To minimize the chance of even minute quantities of fission products or activation products being released, the reactors have five distinct "barriers". These barriers are intended to prevent any dispersal of irradiated fuel, either during normal operation or

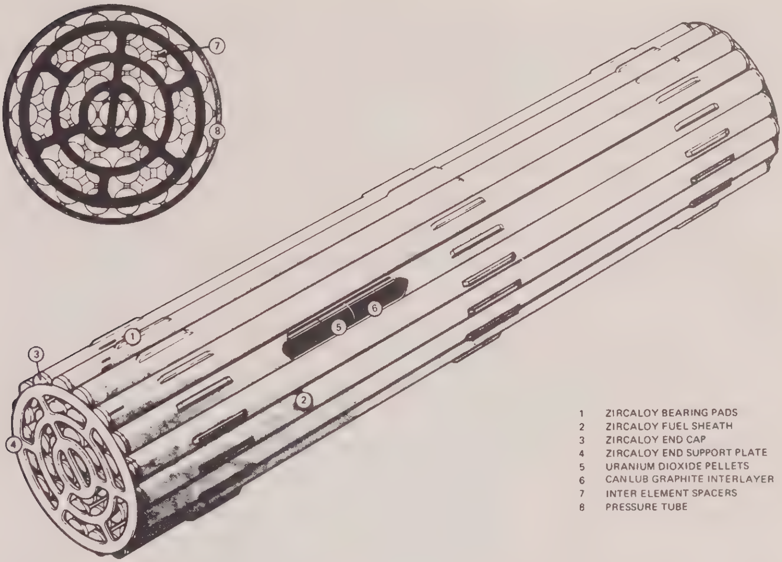

Figure 8. A fuel bundle, consisting of thin zircaloy tubes (fuel rods) that are loaded with uranium oxide pellets and then sealed. A full fuel charge for one reactor at the Pickering generating station is 4,680 bundles. (Source: Atomic Energy of Canada Limited)

in the event of the rupture of a fuel bundle or a stoppage in the flow of coolants.

The first barrier is built into the fuel itself, which is a compressed sinter of uranium pellets of a ceramic nature; diffusion of radioactive components to the surface layers of this sinter is relatively slow, even at operating temperatures. The second barrier is in the form of tubes made of the element zirconium which shield the fuel pellets. The tubes are free of cracks and designed to withstand internal pressure and stress from thermal cycling. The encapsulated fuel pellets are combined into bundles which are isolated inside pressure tubes that contain coolant and can be sealed off to minimize any dispersal of active fuel or of coolant should the fuel sheathing be ruptured; that is the third barrier. The fourth barrier is a gas-tight enclosure, or building, surrounding the reactor vessel. This enclosure can be sealed off to contain the radioactivity and it can either be connected to a large vacuum building whose purpose is to "draw" in possible gaseous releases or "dowsed" with water to clear out any suspended airborne

radioactivity and to keep the pressure low inside the reactor building. Finally, air space is used to protect the public, which is kept at a safe distance from the reactors.

Thus, in the event of an incipient perforation of the fuel sheathing or of a pressure-tube seal, radioactivity cannot leak out or be discharged from the ventilator of the plant. The plant is designed, and the operating procedures are established, in the expectation that minor incidents of various kinds *will* occur in due course and must then be prevented from causing any damage. This philosophy is quite different from one that assumes that a foolproof or operator-proof system, in which accidents and human failures cannot occur, can be designed.

The standards that have been established for the design and fabrication of CANDU reactors are high enough that losses of radioactivity and of coolant heavy water, while detectable, are quite low. Moreover, environmental monitoring data indicate that there are no large variations from day to day in radioactive emissions. Various kinds of monitoring devices are used in the exhaust ventilator, away from the reactors but inside the plant boundaries, and at greater distances from the plant.

Because there is a mixture of radioactive components in the emissions of a large nuclear reactor, it is necessary to identify those that could endanger the health of the nearby human population. The ways in which the various radioactive atoms disperse in air, water, soil, and vegetation must be taken into account, and the pathways identified by which they could conceivably reach animals and man. From a knowledge of the relevant dilution, dispersion, and concentration factors, and of the safe levels of the individual atoms in food chains, it is possible to estimate what are called "derived release limits". Licensing regulations for reactors require operators to ensure that only a small fraction (e.g., less than 1 per cent) of the derived release limits are, in fact, escaping from the plant; in that way, the exposure of the public to radiation is kept down to almost negligible levels, and the doses are kept small in comparison with those delivered by medical and dental X-ray equipment and colour television sets.

Concern is expressed about the danger of a major accident involving serious damage to the structure of a reactor and the release of large quantities of radioactivity. Because of the immense number of radioactive atoms held in an operating nuclear power plant – mostly fission products, actinides, and activation products – the possibility exists of massive contamination in the plant

buildings, on the plant site, and beyond – in public areas. Engineering tests in pilot plant systems in which defective components have been deliberately used, carried out as a licensing requirement to test the systems for hazards, have indicated that while various minor incidents are possible a major physical disruption is highly unlikely. An estimate of the chances refers to one such accident in many thousands of reactor-years of operation. Only a few minor accidents have occurred in the 15-20 reactor-years of accumulated CANDU operating experience. There has been no major reactor disaster involving injury or death to the public.

It is obviously impossible to state unequivocally that a well planned act of sabotage by a knowledgeable person, or a massive sudden failure (for example, of the main piping carrying cooling water) could not lead to a serious accident that might result in substantial damage to an operating CANDU reactor, and a release of radioactivity. A sudden stoppage of the flow of the coolant is probably the worst conceivable CANDU operating accident, and to minimize the possibility of that happening emergency systems are provided for cooling the core of the reactor.

No one has tried to estimate the probability of a major accident to a CANDU reactor, but a safety analysis made in the United States has estimated the relative risks of fatalities from nuclear accidents and other domestic and industrial hazards. (This is the so-called "Rasmussen Study" of nuclear power plant safety.)

Possible annual fatalities among 15 million people living within 25 miles of a reactor site.

Type of accident	Number of fatalities
Automobile	4,200
Accidental falls	1,500
Fire	560
Electrocution	90
Lightning	8
Reactor	2

The consequences of a major nuclear power accident are not likely to be as catastrophic or devastating as some opponents of nuclear power have suggested. Considering CANDU's vacuum buildings and the provisions for physical containment of radioac-

tivity within the reactor and the buildings, it seems unlikely that any massive quantities of radioactivity would be instantly released. Undoubtedly, some releases would occur, and emergency contingency programs would have to provide for rapid assay of samples by monitors situated around the reactor; residents of the immediate vicinity could then be evacuated before there was any danger of them being exposed to unacceptable doses of radiation. Existing licensing requirements call for the preparation and testing of detailed contingency programs to efficiently cope with any such major accident. Contingency programs deal with the provision of emergency monitoring equipment, communications networks, aircraft, and pre-selected sites for monitoring airborne and fallout radioactive atoms, contaminated soil, vegetation, livestock, and water supplies.

A conservative view of the possible consequences of a reactor accident is supported by the history of reactor accidents in Canada – not only by the very lack of any major reactor accident but also by the rather minor consequences of the 1952 and 1958 incidents at Chalk River and of several incidents with nuclear power reactors. In these incidents, releases of radioactivity to the atmosphere were not large, and contamination outside plant boundaries was barely detectable. In none of these minor accidents to date with reactors in Canada was there any significant human injury.

Thus, while there is some concern about the possibility of a major reactor disaster, and much has been written on the subject, it is more likely that the worst conceivable accident would not pose a major radiation hazard to the citizens of Ontario. The experience gained during the period when CANDU was being designed and tested for safety provides a basis for some confidence about the essential safety of future CANDU plants.

The Managing of Radioactive Wastes

Long after nuclear fuel has served its purpose of generating fission energy, it remains highly radioactive, and every nuclear power system must have arrangements for the long-term storage in a safe and protected place of the large amounts of radioactive waste that are produced. Smaller quantities of another kind of radioactive waste, called "low-level waste", are also produced in the reactor system and must be removed from it from time to time. Most of

Nuclear power stations at Pickering, on Lake Ontario east of Toronto (above), and on the Bruce Peninsula midway between Kincardine and Port Elgin (below). Four reactors at Pickering have been in service since 1973, with a total installed capacity of 2,160,000 kW; the size of the station is to be doubled by 1983. At the Bruce station, the projected installed capacity from four reactors is 3,200,000 kW. The Bruce development has one heavy water plant in operation and two more under construction. (Source: Atomic Energy of Canada Limited)

this low-level waste can be stored on the property of the nuclear plant, but the spent fuel can be kept there for only a short time and must be transferred to a facility expressly designed for long-term management of radioactive waste.

Spent fuel from CANDU plants is stored at present in water-filled pools. These pools will be able to handle all of the spent fuel that is likely to accumulate until the mid 1980s, and after that it will be necessary to transfer some of the older fuel to long-term storage. In the future, spent fuel will probably be kept in pool storage at the reactor sites for about five years, to permit a large part of the radiation to die away. Transportation of the spent fuel to long-term storage sites will then be considerably simpler and less hazardous.

Storage pools are designed to prevent the escape of radioactivity from fuel bundles placed in them. As the bundles are moved from the reactor at the end of their useful lifetimes, they are immersed in secondary pools, and any bundle which through damage or malfunction is releasing radioactivity to the water can then be placed in a sealed container before being transferred to the main storage pool. At a typical CANDU plant, such as the Pickering or Bruce plant, the storage pools have a capacity for about 10 years' production of spent fuel bundles and are not much larger than a standard Olympic swimming pool complex.

Some risk is associated with the transportation of spent fuel from the plant sites to the sites designed for the management of radioactive wastes. Massive lead coffins are used and they are built to withstand road or rail accidents without releasing any of their cargo. There may well be concern about the possibility of plutonium shipments being hijacked, but a hijacking of spent uranium fuel is unlikely because the material would be difficult to use and the quantity of fissile material would be too small to be useful.

Two different kinds of arrangement for "intermediate" storage (of about 25 years) have been proposed, and developed to the stage of trial units. One of these arrangements involves concrete canisters, or silos, about 7 feet in diameter and 14 feet high, each with a capacity of up to 216 fuel bundles, or about 4,000 kilograms of spent fuel. If all CANDU fuel produced in Ontario up to the year 2000 were to be placed in rows of such canisters, it is estimated, an area of less than 400 acres of land would be required, and the cost would be $3 or $4 per kilogram of uranium, compared with an original cost of about $100 per kilogram of the original fuel. Provision would be made to seal fuel bundles into liners, so there

should be no escape of radioactivity. In this method, radiation shielding is achieved by the 30-inch walls of the canisters and by a lead jacket surrounding the bundles; the radiation heat is dissipated by convection and wind action.

The other arrangement for intermediate storage involves farms of water-filled pools similar to the short-term storage pools at the reactor sites. One of the worst conceivable accidents to an intermediate storage facility would be the crashing into it of a large aircraft; clearly, a farm of concrete canisters would be relatively unaffected whereas the fuel in a farm of water-filled pools would probably be broken up and scattered about.

The ultimate storage, or disposal, of irradiated fuel bundles will probably be carried out underground, beginning in the next century, in stable rock formations. Geological formations that have been free of stresses for long periods will be penetrated by drilling, and fuel bundles grouped in cans will be placed inside them.

One of the reasons why spent fuel is not transferred directly from the short-term storage facility at the plants to the ultimate disposal sites is the need to hold open the option to send the spent fuel to reprocessing plants where the plutonium content could be retrieved for recycling. For that reason, it is a stated requirement at present for Canadian waste management facilities that retrievable storage be used for 50 years.

It has been stated by Peter Dyne, a Canadian expert on radioactive waste management, that, after 50 years of cooling, the concentration of radioactivity being then returned into the rock layers will be no greater than that of the ore from which the fuel

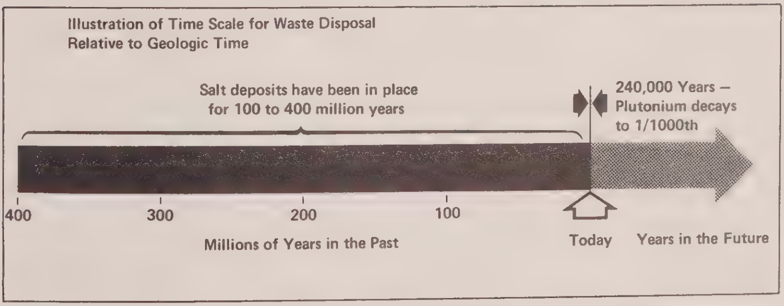

Figure 9. Comparison between the time required for the decay of radioactive waste and geologic time. Granite formations (not shown) have been in place for about 2,000,000,000 years. (Source: Atomic Energy of Canada Limited)

was made. Man will have mined uranium ore, extracted useful energy from it, stored it for a period of time, and then returned it to the Earth's crust with no net addition to the global inventory of radioactivity.

On the other hand, low-level wastes are disposed of by burial in soil beds that are able to trap radioactive components and prevent them from being leached by soil water and carried into nearby streams or lakes. Such waste disposal sites (of which there are fewer than a dozen in Canada) are closely monitored and are perpetually set aside for the burial of radioactive waste. Contaminated solids and ion-exchange resins, as well as air filters and workers' gloves and other clothing, are buried in dry pits. Experience with the burial of solid wastes has shown that clays, sands, and organic soil components can bind most radioactive atoms tightly. Diffusion rates of only a few feet in 10 years are typical.

It must be noted, however, that recent experiences at Port Hope, Elliot Lake, and Uranium City have shown that the burial of radium-containing wastes can lead to problems, because of the leachability of radium and the ability of radon to diffuse through layers of soil and into buildings. The proliferation of nuclear power reactors will undoubtedly lead to the setting up of more burial sites for waste. Because of the risks involved in transporting low-level wastes, many of the sites will probably be on or adjacent to power plants.

The health and environmental risks from the mining and refining of uranium ore are probably greater than those associated with the normal operating of reactors and the handling of wastes. This is so despite the fact that the concentrations of radioactivity in uranium are extremely low compared with those in irradiated uranium fuel or radioactive wastes. Yet there are fewer regulations for the containment of radioactive particulates and gases in uranium refining and in the disposal of mill-tailings and liquid wastes than there are for the operation of nuclear power systems. The ventilation in uranium mines and the respirators that have been supplied to miners have apparently not been adequate precautions against the ingestion of radon gas and its daughter products. Unless new and effective guidelines are introduced for the protection of employees from radioactivity in mines and mills and for the isolation of areas used for the disposal of mill wastes, the uranium "front-end" technology, as the mining and milling operation is called, may continue to be nuclear power's chief threat to human health.

This situation might change if Ontario were to decide to go into the business of reprocessing nuclear fuel. Known reserves of natural uranium will, it has been estimated, last for 50 or 60 years. If it were found necessary to extend the useful lifetime of this resource, then there would have to be a program for the reprocessing of spent CANDU fuel. Use can be made of the plutonium that has been built up in spent uranium fuel and of the thorium that is available in large quantities in Ontario as a by-product of the refining of uranium ore. Mixed plutonium-thorium oxide can replace uranium as the fuel for CANDU reactors, and, to further extend the cycle, the thorium can then be reprocessed to provide U-233.

Such large-scale reprocessing would involve considerably greater risks of environmental emissions, incidents causing radioactive contamination, and the theft or hijacking of plutonium. Also, the waste products from reprocessing would be much more difficult to dispose of than the fuel bundles from "once-through" fuel systems like the one now in use in Canada.

Technology has been developed for incorporating reprocessing wastes that contain fission products and actinides other than plutonium into glass-like blocks that can contain the radioactive atoms for long periods and can resist leaching. Special procedures are also necessary to trap the large quantities of radioactive gases including tritium that will be released when the spent fuel is dissolved in preparation for reprocessing.

Most of the chemical technology necessary for reprocessing is available, but the precautions necessary to ensure incident-free operation will probably have to be more stringent than the present-day ones for the operation of nuclear reactors and the "once-through" handling of fuel. At first glance, it would seem that efforts should be made instead to improve the neutron-economy in CANDU reactors and the stability of uranium fuel during irradiation, so that more efficient use is made of uranium, and the need to use plutonium and breed thorium thereby obviated.

To summarize, appreciable risks are associated with the nuclear fuel cycle, and particularly with the "front-end" and "back-end" aspects of the use of uranium, plutonium, and thorium in CANDU reactors. During normal operations, the hazards at all stages of the system are probably quite acceptable, but the potential for mismanagement and for incidents that might result in contamination is real, unless there are adequate safety guidelines and licensing procedures, along with the monitoring, inspection, and

vigilance necessary to ensure compliance.

The Economics of Nuclear Power

The capital costs of CANDU plants are much higher per kilowatt of generating capacity than those of fossil-fuelled plants. This is because of the need to use special materials and to meet demanding specifications of manufacture and construction. The costs of installing the heavy water and the initial charges of fuel are also high. Heavy water and uranium each cost about $20-$30 a pound. Over 100 tons of heavy water and 25 tons of uranium are required. Thus the capital costs of a CANDU plant are about twice those of a comparable coal- or oil-fired power plant.

The major difference, economically, is in the fuelling, operating, and maintenance costs. Comparing a fossil-fuelled plant and a nuclear plant that come into service at the same time, the fossil-fuelled plant is twice as expensive as the nuclear plant to fuel, operate, and maintain in the first year, and four times as expensive after 15 years. Another important aspect in cost comparisons is the capacity factor, which describes the past performance of the plant. In fact, the capacity factor measures the actual electricity output as a percentage of maximum designed output. A gross capacity factor of 86.5 per cent was achieved in the Pickering nuclear power plant in 1975, and if that sort of performance can be maintained the relative cost advantage of that station over other stations will be significantly improved.

Another point of contrast is the impact on the Canadian economy resulting from the construction and operation of the two kinds of plants. Over 90 per cent of a CANDU plant can be built and supplied in Canada by Canadians. On the other hand, fossil-fuelled plants require many imported components, and the fuel (coal) for some of them comes partly from outside the country.

Opponents of nuclear power insist that it is virtually impossible to determine its true costs because CANDU development costs and the value of Atomic Energy of Canada Limited consulting services are not fully reflected in estimates like those cited above. Rough estimates based on cumulative Atomic Energy of Canada Limited budgets during the years of CANDU development indicate that $1,000,000,000 were probably invested. Comparable development

costs for a modern coal-fired plant, such as the Lambton plant, were probably several times that amount.

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Fuels for Power Generation

Leonard Bertin

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Canadians consume more energy than the people of any other country in the world except the United States.[1] We use more electricity per head than any nation except Norway and 25 per cent more than our neighbours to the south.[2] In fact, about one-quarter of all the money we spend is used to purchase and operate equipment to provide heat, light, and transportation, or as a substitute for muscles.[1] Nor is this surprising, in view of our harsh climate and our relative affluence.

If Canada's population doubles over the next 40 years, as some demographers believe it could,[3] and if the per capita demand for electricity continues to double every 20 years, as it has been doing, then we can expect the total requirement for electricity to double during each of the next few decades. Demand could rise even more steeply if the prices of fossil fuels rise disproportionately in the meantime.

Until quite recently, Ontario Hydro engineers were happy about the accelerating demand for electricity. They believed in electric power and they realized that, the more energy they were called upon to supply, the lower could be the cost of each unit of electricity they produced. Their record in meeting the rising demand has been quite remarkable, and the result has been the creation of one of the largest and finest public utilities in the world. Cheap electric power has been one of the most important single factors in Ontario's industrial growth.

Looking at the matter from a short-term point of view, there was nothing wrong with this. Energy has always played a central role in the life of Man. It has been the most important factor in

determining the standard of living of any civilization. Thus, the primitive cave man, living a hand-to-mouth existence on an irregular diet of 2,000 to 3,000 kilocalories a day, had only his own muscles to rely upon – the equivalent of between one-tenth and one-quarter of one horsepower. When he was cold, he had no fire to warm him and could only snuggle more tightly into the skin of some wild beast he had managed to stalk and kill with his own hands.[4]

Tremendous improvements in living standards came, successively, with the discovery of fire, the domestication of animals, and the cultivation of the soil. As Man learned the art of cooking, a wide variety of previously indigestible plants, fruits, roots, and meats became edible. Man was no longer a lone agent; but was able to feed animals and make them work for him. He had become part of a man-animal system. The change was reflected in an increase in Man's total energy intake that has since been computed at something like 10,000 kilocalories a day.

Gradually, Man learned to harness rivers and use sails and windmills and then, progressively, to exploit the riches of coal, oil, and natural gas and to convert these at will into electricity. As a result, the average intake of today's man-animal-machine system has been computed at something like 200,000 kilocalories a day. Increasing dependence on mechanical devices, the depletion of reserves of raw materials, and the development of nuclear power will encourage even greater calls on energy, including its use to promote chemical synthesis. We may well end up by meeting most of our daily needs from such basic raw materials as air, water, and limestone.

Water and Other Sources

In Canada, early settlers had ample supplies of wood with which to cook and keep warm and they used water-wheels whenever possible to mill grain and saw wood. In Nova Scotia, particularly, even as early as 300 years ago, they also used coal. By the end of the 19th century, coal was being mined in significant quantities, in part to meet the needs of expanding railroads that were by then available to distribute it.

But events were already taking place just south of the border that were to change the way of life of the people of Ontario. On

Sir Adam Beck-Niagara generating stations No. 1 and No. 2 eight miles downstream from the Falls (above), with a combined capacity of 1,815,000 kW; a special feature is a man-made reservoir that stores water to be released at times of peak demand. Below is a view of the Little Long generating station on the Mattagami River 42 miles north of Kapuskasing; the capacity of this plant is 121,600 kW. (Source: Ontario Hydro)

November 15, 1896, the mayor of Buffalo threw a switch that enabled electric power from a generating station below Niagara Falls to energize the newly-created 20-mile transmission system of the City of Buffalo.[5] It was the farthest electricity had ever been transmitted for commercial purposes and the development was to set a new trend. Some historians have claimed that the event marked the beginning of what was to be a second Industrial Revolution.

However, it took the determination of a far-sighted politician, Adam Beck, and a great deal of pressure from the public at large to achieve the single most important step in Ontario's industrial development.[6] This was the passage in the legislature in May 1906 of a bill entitled: "An Act to Provide for the Transmission of Electric Power to the Municipalities". This act created a new administrative body called the Hydro-electric Power Commission of Ontario,

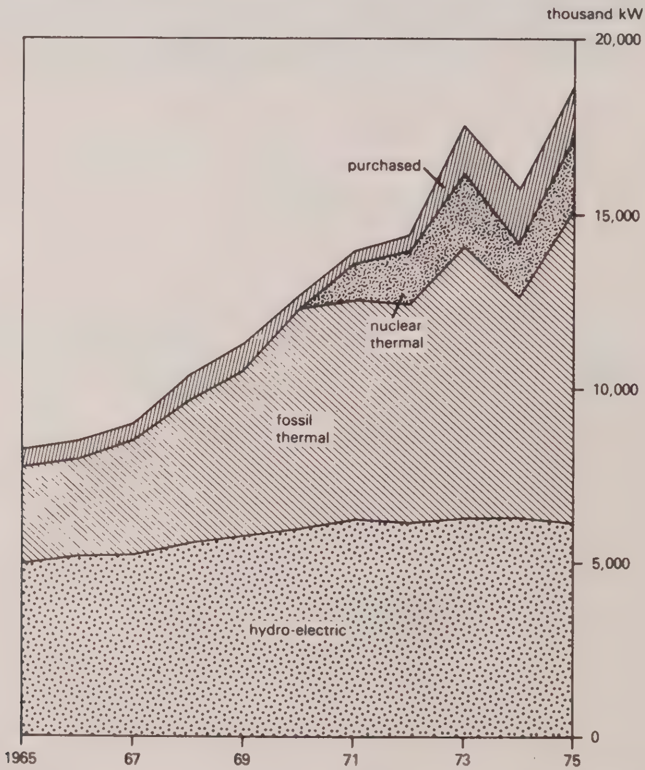


Figure 1. Dependable peak capacities of Ontario's sources of electric power. (Source: Ontario Hydro)

whose mandate was to provide cheap electricity to all the people of Ontario. Soon a vast grid of transmission lines was created to link all the major industrial centres.

As the convenience of electrical power came to be appreciated, and the variety of electrically powered devices available to a rising population expanded, the demand for electricity increased in proportion. At first, the demand was satisfied by the building of more and larger hydro-electric plants, and soon "hydro" became synonymous in Ontario with electricity. But, even in the early days, geographical considerations required that hydro-electric stations be supplemented by stations that burned coal to generate steam to drive generators.

By the early 1960s, Ontario was beginning to use significant quantities of coal to generate electricity. In 1963, for example, hydraulic generation accounted for about 70 per cent of Ontario's total capacity.[7] The rest came mainly from coal-burning stations. By 1973, only a decade later, power from hydraulic sources was meeting only 50 per cent of the expanding demand. The percentage is expected to shrink to less than 30 by 1980, with nuclear power providing more and more of the balance (see Figure 1).

Ontario's need for energy, measured in gigawatt-hours (thousands of millions of watt-hours) is expected to increase as follows:[8]

1975	87,891
1980	135,585
1985	184,385
1990	255,340
1995	346,646

At present, as Table 1 shows, Ontario Hydro depends, and expects to continue to depend, on a variety of sources.[9] Some of these sources will be unable to expand significantly to help meet the increasing demand.

There are a number of factors that will affect the picture, including the extent and geographical location of reserves, the problems of transportation, political considerations, and the dependability of supplies. I propose to review these factors in relation to the various potential primary sources of energy, including some that have not yet been attempted on any significant scale in Canada.

Hydro-electric power has played an enormous role in Ontario's development and will continue to play an important role in the

Table 1. Forecast Distribution of Ontario Hydro's Annual Energy Production (percentages)

Year	Coal	Residual oil	Natural gas	Uranium	Hydraulic	Electricity purchases	Total
1975	24	1	6	13	39	17	100
1980	34	6	3	28	26	3	100
1985	27	5	2	47	19	0	100
1990	24	3	2	58	13	0	100
1995	21	2	1	66	10	0	100

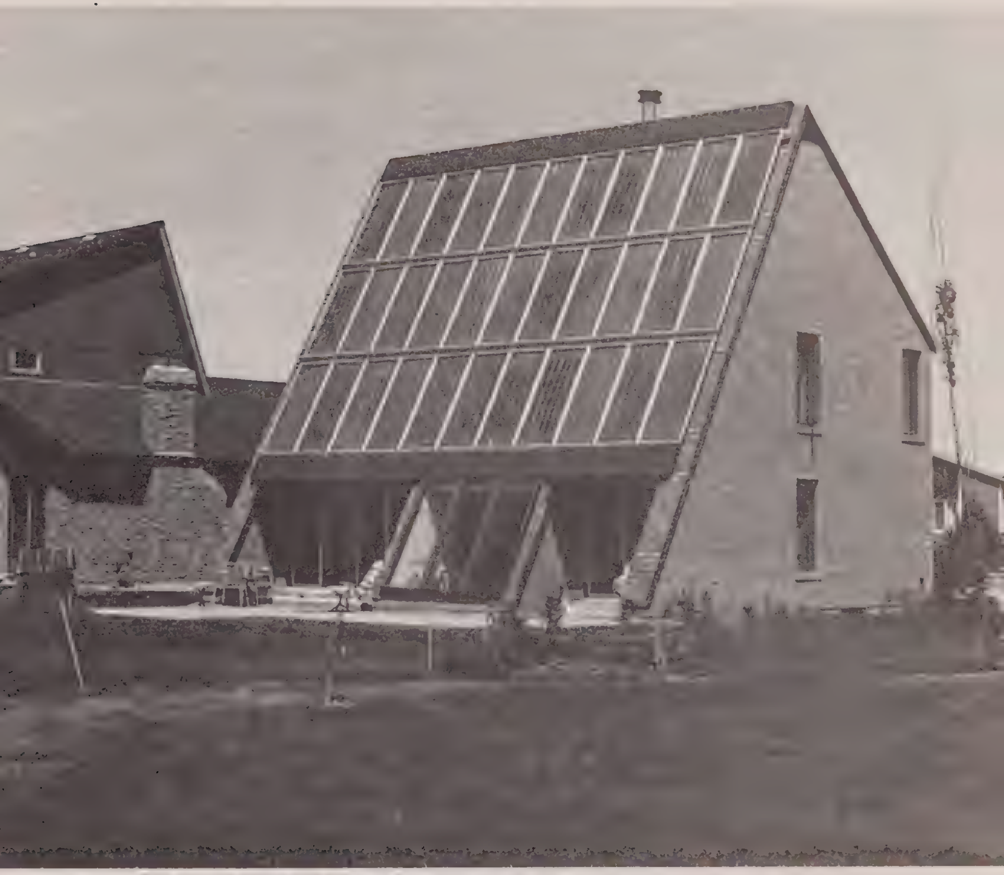
future, although most of our hydraulic resources are now being utilized. There are significant new hydro-electric installations and projects in other provinces. They will all play tremendously important roles in the development of Canada, and one of them, the Hydro Quebec Baie James project, may one day make a massive contribution to the Ontario economy. It could well be, too, that new technology and more research and serious thought will open up ways to develop some of Ontario's own hitherto unexploited reserves of hydraulic power.

The ocean tides represent a form of solar energy, but I will not explore this resource here, because it is only of indirect concern to Ontario.

Looking for more direct ways of exploiting solar energy, we are confronted with the obvious fact that it is both a highly dispersed form of energy – the task of reconcentrating it is bound to be expensive – and an unreliable one.

Unfortunately, the trapping of solar energy economically is not a simple task. At present, only a few specialized applications for solar energy exist – such as air-conditioning and water heating and cooking, and the generating of electricity to power apparatuses in orbiting satellites. Very little effort has been put into the problem to date.

The problem is partly one of collecting solar energy when it is most available (and often least wanted) and storing it for the time when it will be most required. As technology improves, this may become feasible though not necessarily economical. It has been calculated, for example, that it would require between 100 and 300 square miles of solar collectors to meet the December needs of a city like Toronto.[10]



The Meadowvale solar-heated house in Mississauga, near Toronto. The solar heating system is calculated to provide 60-70 per cent of the heating requirements of the house. It is a combination of a direct solar heating system and a solar-assisted heat pump. (Source: Douglas Lorriman)

Wind is another vast, but unfortunately not dependable, source of power. Although it is true that wind and water were the chief sources of motive power before the Industrial Revolution, the mechanical and electro-chemical problems of first capturing and then storing this energy in a cost-efficient way are manifold. An official of Atomic Energy of Canada Limited recently estimated that 160,000 windmills, each 100 feet in diameter, would be required to supply the needs of Toronto. At an average deployment of three per square mile, it would be necessary to have 53,000 square miles

of windmills, which would take much of southern Ontario, just to satisfy Toronto.

Geothermal steam and the heat of volcanoes are obvious possibilities that deserve exploration. The main problem is their scattered distribution. In the whole world, there are only a few locations that have any considerable possibilities, the closest to Ontario being the hot springs in the Rockies. One plan for harnessing geothermal energy envisages the drilling of a hole deep down into a very secure stratum of rock and exploding a nuclear device there from time to time. These explosions would so raise the temperature that the surrounding rock would be transformed into glass, which would later fall inwards and end up at the bottom of the cavern created by the explosion. The same glass would trap in a very permanent fashion most of the radioactive products of the explosion. The next step would be to introduce water into the cavity. The water would, of course, be transformed immediately into superheated steam, which could be used to drive turbo-alternators and produce electricity. There is little doubt that such a system would work, provided that due care was taken to select appropriate geological structures, and there is no foreseeable hazard to the environment. Nevertheless, this approach is a pretty far-off prospect and it could easily be rendered obsolete by new developments.

Coal

When it became clear that hydraulic sources of primary energy could not meet all of Ontario's needs, the obvious commodity to turn to was coal. First of all, there was lots of it, if not in Ontario, certainly not far south of the border. Secondly, the demand for coal elsewhere had suddenly decreased. After being used exclusively on the railroads for many decades, coal-burning systems were replaced, first by oil-fired systems, which were simpler, easier on crews, and much cleaner, and then by diesels. At the same time, new technology in the form of the automated burner led to the eclipse of coal in residential and commercial heating and in the industrial field, and the expansion of electric power generating was accompanied by a dramatic increase in the use of coking coal for steel-making.

Table 2 shows how the consumption of coal has varied since

Table 2. Consumption of Coal in Canada (millions of tons)

1930	1940	1950	1960	1970	1973
15.5	18.2	19.1	11.0	16.6	22.6

Source: Statistics Canada

1930. To meet the growing demand after 1960, imports of coal from the eastern United States were increased from 4.5 million tons in 1964 to 7.5 million tons in 1974. Coal has many advantages as a fuel for use in large generating stations. It has been used for so long that the technology is highly developed. The capital cost of coal-burning stations is lower than for hydraulic or nuclear stations. Coal-fired stations are flexible; they can be switched on and off and used at varying levels of intensity to meet varying demands from day to day. And coal is abundant in Canada, although most of our best coal is in Alberta.

Coal has two basic and important disadvantages. First, large quantities by volume and weight are required and this means that extensive and expensive transportation and handling systems are necessary to move it from the mines, which are often located in remote and sparsely populated areas, to the generating stations, usually located close to populous centres. Secondly, the use of coal poses environmental challenges, both in the mining areas and at the generating stations.[1] As Milan Nastich, vice-president (resources) of Ontario Hydro, has pointed out, both of these challenges can be met by dedicated and sophisticated work.[11]

Ontario government regulations require that studies be undertaken to determine the likely effect of any proposed new mine on the local population, surface drainage, wildlife, and vegetation. Mining plans have to be approved in advance and must deal satisfactorily with each of those requirements. Programs and procedures for surface reclamation must also be approved in advance and are subject to inspection while mining is going on. Using modern techniques and technology, mining companies can meet these requirements and avoid the problems of the past. Likewise, the use of high-efficiency fly-ash precipitators and the blending of coal to ensure a satisfactory sulphur content can greatly relieve the problem of stack emissions.[11]

To be economical for the generating of electricity, Nastich has indicated, coal must possess certain qualities. It should be high in

heat content in relation to the cost of mining and transporting it, so as to minimize the cost of delivered energy; and, for the same reason and to prevent problems in handling it in cold weather, it should have a low water content.

It should be low in ash content, because of the high cost of handling and disposing of ash. It should also be low in sulphur content, to meet the strict government limits on sulphur dioxide and sulphur particles in the atmosphere around stations, but it should contain some sulphur because this makes it easier to extract the fly ash.

The coal should contain sufficient volatile material to promote efficient combustion and it should be easy to grind and pulverize for injection into furnaces. It should also be free-flowing, with as little dust production as possible and a minimal tendency to freeze.

For future supplies of coal, Ontario has long-term contracts with suppliers in Pennsylvania and West Virginia for more than 10 million tons a year. These contracts are as follows:[12]

	Tons per year	Expiry date
Consolidation Coal Company	6,000,000	1986
Eastern Associated Coal Corp.	2,500,000	1984
Various other companies	1,750,000	1979-80

It is expected that most of the contracts will be renewed or replaced when they expire.[13] Deliveries under a further contract with United States Steel Corporation are scheduled to begin late in 1976 and should reach a rate of 3,000,000 tons a year by 1979. This contract should furnish a total of 90,000,000 tons over a 30-year period.

By 1980, Ontario should also be receiving between 4,000,000 and 8,000,000 tons of bituminous coal each year from western Canada. It will not be of the same high quality and energy content as coal from eastern United States sources. However, it will be used in new generating stations that will have been specially designed for it. Ontario Hydro may also use lignite from the Onakawana deposits of northern Ontario. Lignite reserves are estimated at up to 200,000,000 tons, but because of the poor quality of these geologically younger deposits they will make a relatively small contribution to the total power supply if and when they are developed.

Although Nova Scotia made a significant contribution to

Canada's coal needs, especially in the era of the coal-burning locomotive, the remaining known reserves in eastern Canada are limited and there is no assurance of long-term supplies. The offshore potential in eastern Canada has still to be assessed, but it is doubtful that coal from that source could compete in price with U.S. coal, or in security of supply with Canadian continental coal.[14]

Present supplies of coal from the U.S. come by unit trains throughout the year to terminals at Conneaut and Ashtabula on the south shore of Lake Erie. Then, during the lake shipping season, this coal is moved by self-unloading lake ships to stockpiles at the various coal-fired stations in Ontario.[15]

Planned coal supplies from western Canada will be moved by unit trains to generating stations that are under construction at Thunder Bay and planned for Marmion Lake in northwestern Ontario, and will also be trans-shipped from Thunder Bay to various locations in southern Ontario.

Oil

Oil is an ideal fossil fuel for electric power generation, when the price is right and as long as the sulphur content is low. In convenience, it ranks second only to natural gas as a primary fuel. Like gas and coal, it is a prolific source of hydrocarbons that are ideal starting points for the production of a great variety of drugs, foods, dyes, paints, solvents, synthetic fibres and construction materials, artificial rubbers, plastics, and explosives. Its potential is so great, in fact, that one has to question the rationale behind any process that merely transforms it into energy and carbon dioxide and water.

Currently, along with natural gas, oil provides almost all of the non-electrical requirements of Ontario's industrial, residential, commercial, and transportation sectors, with the significant exception of steel, which uses coke.

If we ignore for a moment the disservice we do to posterity by burning oil to generate electrical power when there are more sensible alternatives, then it has to be said that oil is a very good fuel to work with, when its sulphur content is low. But indigenous reserves are being depleted at a rate that far surpasses our discovery of new reserves. Furthermore, alternative sources can

The coal-burning Lakeview generating station on Lake Ontario just west of Toronto (above); the total capacity is 2,400,000 kW. Below is the Lennox generating station, 20 miles west of Kingston, Ontario's first oil-fired plant, with a projected total capacity of 2,295,000 kW. (Source: Ontario Hydro)

hardly be regarded as secure in the light of a succession of crises in, and pressures from, the Middle East, where most of our imported oil comes from. Venezuela, our next best source, is in South America, a region that is probably without parallel anywhere in the world for political instability.

This points to the conclusion that it would be most unwise to construct a chain of expensive thermal generating stations that were dependent on oil until long-term domestic reserves are shown to be a lot more promising than they are at present.

At present Ontario Hydro uses oil for only one per cent of its fuel requirements. It has a contract with Golden Eagle's refinery near Quebec City, which uses Venezuelan and Middle East crude oil. This contract, which is for a nominal 5 million barrels of residual oil a year, expires in 1979.[16] (Residual oil is the residue after crude oil has been refined to obtain gasoline, heating oil, and various other products.) In addition to the supply of residual oil derived from foreign crude, Ontario Hydro and Petrosar Limited of Sarnia, a subsidiary of Polymer Corporation, the Crown petrochemical company, have exchanged letters regarding the supplying of 7.3 million barrels per year of low-sulphur residual oil to be derived from western Canadian crude oil. The supply will extend over 15 years, until 1991, and will be renewable for three-year periods thereafter.

Residual oil from the Golden Eagle refinery and from the Petrosar installation is being moved at present by rail. Other alternatives are under study, including the use of lake tankers, pipelines, and interconnections with the Interprovincial Pipeline. A major consideration is that the transportation method must be flexible, to accommodate a wide range in the volume, since oil consumption can vary greatly under certain conditions and over extended periods. Thus, to help meet the sustained high-output requirements, as well as for normal operating reasons, substantial storage facilities are provided at oil-fired generating stations.

Generally speaking, the supply of residual oil tends to be more reliable than that of crude oil, because of the greater demand for other refinery products used in transportation and as starting points for many petrochemical products.

Currently, Ontario Hydro's oil supply program envisages primary reliance for residual oil on the Petrosar refinery, which draws its crude from western Canada, and on the Golden Eagle refinery. Spot purchases of residual oil, or crude oil if necessary, can provide additional supplies. Both of the oil-fired stations of

Ontario Hydro – Lennox, with two of its four units already in service, and the proposed Wesleyville station – have been designed to store and use both residual oil and crude oil. The long-term availability of oil depends on the development of additional domestic sources and on the continuation of imports.

It is expected that, by 1983, supplies of crude oil from western Canada will no longer be capable of satisfying traditional domestic markets, even with the movement of 250,000 barrels a day to Montreal through the recently extended Sarnia pipeline. By 1984, eastward movement of oil along the Montreal extension will cease, and by 1986 the same pipeline will be called upon to pump 300,000 barrels of oil a day in the other direction. To meet this shortfall, it will be necessary to build new tidewater terminals in the lower St. Lawrence and to modify the Sarnia refineries so that they will be able to operate on heavier crude with a higher sulphur content. The cost of each of these two developments will be around $200 million, in 1975 dollars.

There is an alternative: the development of additional oil supplies within Canada, together with the pipelines that would be needed to move them from remote areas such as the Arctic and the Atlantic coast.

Natural Gas

The very same considerations apply to natural gas, the most convenient of all fossil fuels. Its present use, as far as Ontario Hydro is concerned, is limited because of its high cost and the uncertainty of future supplies. In consequence, gas is used at present in only one generating station, the Richard L. Hearn plant in Toronto, which has four 100 MW units fuelled solely by gas and four 200 MW units that can burn either gas or oil.

To satisfy the demand of these units, Ontario Hydro has a contract with Consumers' Gas Company to supply 49 billion cubic feet of natural gas per year until November 1981. The hope is that, by then, declining supplies from Alberta will be offset by gas from the Arctic. This supply will depend, of course, on the construction of a pipeline up the Mackenzie Valley from the Mackenzie delta, from offshore sources in the Beaufort Sea, and from the arctic islands. Then it would come to Ontario via TransCanada PipeLines and the Consumers' Gas system. Continuity of service would be

assured by extensive underground storage facilities in Ontario.

If major new finds are made, natural gas could have an important additional role in Ontario as a blending fuel in generating stations that are forced to burn coal with a high sulphur content. It must be anticipated, however, that the cost of natural gas will rise considerably, and this will affect its use.

Fossil Fuel Supplies

In this situation, with fossil fuels becoming scarce and ever more expensive, the advances in nuclear technology have occurred at a most propitious moment. It is hard to see what the world would have done without this new source of energy, which opens up vast resources at a critical time and provides an alternative to the profligate consumption of our valuable reserves of fossil fuels. While it will initially contribute to the problem of thermal pollution, it will ease the impact of other pollutants on our environment. Notably, it will contribute no sulphur dioxide or oxides of nitrogen, which are biologically harmful, and insufficient carbon dioxide to have any predictable long-term deleterious effect on world climate.

A problem that has to be anticipated, in connection with oil and all fossil fuels, is that, as reserves everywhere diminish, it will become harder to get supplies with a low (less than one per cent) sulphur content. Provided that the one-per-cent level is not exceeded – and oil with a much lower sulphur content is available from other countries – it will be possible to blend the supplies to produce a mixture that will stay within the environmental specifications laid down for most areas.

Imperial Oil Limited, in a presentation in 1976 to the Ontario Royal Commission on Petroleum Product Pricing, pointed out that a number of major uncertainties need to be identified in looking at the future.[17] For example, the probable effect of increased prices on consumption is not yet well understood, except that it must be assumed that a higher-priced commodity will be used more efficiently. Nor can we yet foresee how far government actions to promote conservation will bring about a reduction in demand.

Figure 2 shows what the effect would be of reducing Ontario's 5.1 per cent annual growth in the demand for energy, which has prevailed since 1960, to 4.5 per cent and to 3 per cent. The higher

rate, based also on a maximum foreseeable rise in population, assumes a moderate impact on demand as a result of rising prices and conservation efforts. The lower rate, based on a more moderate rise in population, assumes a stronger response to demand-reducing forces. The graph indicates that, by 1990, consumption at the higher rate would still achieve a reduction of 10 per cent in total consumption compared with the amount we would be using if the demand continued to increase at the present rate. With the lower rate of increase, a reduction of 25 per cent could be achieved. However, we must bear in mind that the amount of coal used for steel-making, now about 16 million tons a year, could rise to 35 million tons by 1990.

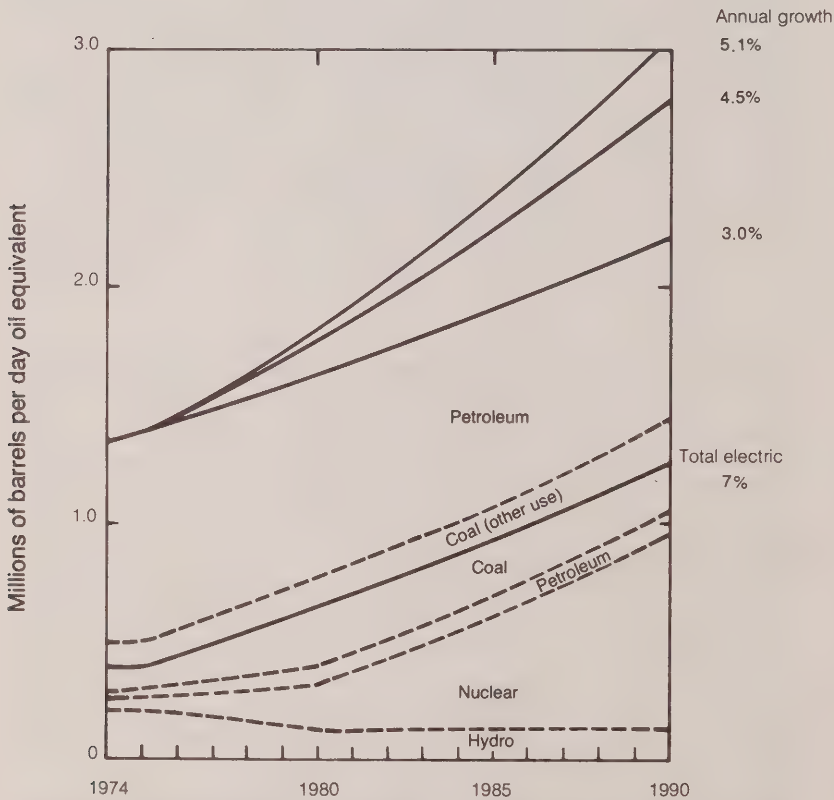


Figure 2. Graph predicting the effect of reducing Ontario's annual growth in demand for energy from the present 5.1 per cent to 4.5 per cent and to 3 per cent. (Source: Ontario Hydro)

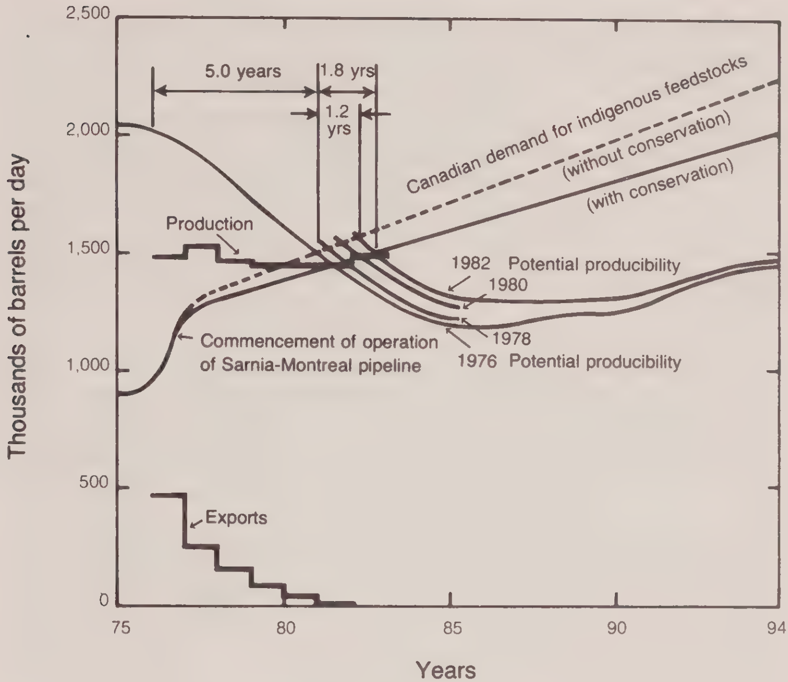


Figure 3. Graph of estimated Canadian producibility of and demand for crude oil, showing that demand will exceed production by the early 1980s. (Source: National Energy Board, September 1975)

Projections developed by the National Energy Board (see Figure 3) show clearly how the rising demand for feedstock will exceed production by the early 1980s. The exact time when this will happen will depend on what new reserves are developed and on the effectiveness of conservation measures.

The National Energy Board has indicated that, if shortages arise, Canadian customers will have precedence over any export commitments, for both domestically produced oil and domestically refined oil. However, the reliability of future supplies of domestic crude oil will depend on what new reserves are found and developed, and on the speed with which technology is developed to exploit the Athabasca tarsands.

It should be explained that all existing thermal stations, whether they burn fossil fuels or depend on the splitting of heavy atoms, are designed to generate steam, which is used to turn turbo-alternators. When the steam has done its job, and to increase the

efficiency of the system, it is condensed back into water and reused. Because of the need to condense the steam, an abundant supply of cooling water has to be available near each thermal power station. In the process of removing the heat from the steam, the cooling water is heated to 15-18°F, or 8-10°C. The amount of cooling water needed can be reduced by the use of cooling towers, but only by paying another environmental price. The towers are enormous, unsightly, and sometimes noisy, as well as costly. They create large amounts of water vapour, which can also constitute a nuisance.

In a station that burns a fossil fuel, the efficiency of the system – the ratio between electricity generated and heat produced – may sometimes be as high as 40 per cent. This still means that, for every unit of electricity generated, one and one-half units of energy will be dispersed wastefully as heat into the environment, in cooling water, or through smokestacks. In a nuclear station, where operating temperatures are at present much lower, the ratio of heat to useful energy is more than two to one. So one of our priorities must be to look for more efficient ways of converting our energy resources into electricity.

Nuclear Fuels

The most striking aspect of nuclear power is the small volume and weight of the fuel involved. For generating electricity, one pound of natural uranium is the equivalent of 15,000 pounds of good bituminous coal. Put another way, one 50-pound bundle of natural uranium oxide fuel rods is the equivalent of 375 tons of coal or 66,000 gallons of crude oil. It is an attractive comparison when you think that, instead of needing dumps containing two to three million tons of coal, or many large oil tanks, either of which would involve continuous movement of ships or trains, a nuclear power station can receive a year's supply of fuel by road in one day.

Nuclear power is obtained by converting into energy the nuclear cement that holds together the component parts of certain heavy atoms. This process occurs inside a nuclear reactor, and in Canada the type of reactor in use is the Canadian deuterium (natural) uranium (CANDU) reactor, which is the key component of what has become one of the world's most successful nuclear power generating systems.

The best example of a CANDU system is the huge nuclear power station now in full operation at Pickering, 15 miles east of Toronto. This station, one of the largest and most dependable nuclear power stations in the world, is comparable to the largest coal-fired station. During the period 1973-5, it filled 16 per cent of Ontario's electricity demand. Based on current prices of U.S. coal, the station had, by March 1976, saved $500 million. An even larger sister station is under construction on the Bruce Peninsula, and it is anticipated that, by 1990, CANDU-type stations will be providing 60-65 per cent of Ontario's electrical energy.[18]

For its nuclear power program, Canada will require large amounts of heavy water and uranium. To bring a 500 MW nuclear unit into operation, about 550 tons of heavy water are required and 100 tons of natural uranium fuel. Furthermore, each year, some 6½ tons of additional heavy water are needed to make good the losses, and about 75 tons of uranium must be replaced.

Canada has large resources of uranium, currently estimated by the federal government at 400,000 metric tons, and a large proportion of these reserves are in Ontario.[19] By federal requirement, enough of these resources have been set aside for Canadian use to provide for 30 years of working life for Canadian stations in operation, stations under construction and committed, and stations planned to be committed between now and 1985.

Ontario Hydro plans to increase its installed nuclear capacity considerably in the next decade, and this will increase its requirements for nuclear fuel. Existing contracts will meet almost all of its requirements for the period 1976-9 and part of its needs through 1985. From 1975 to 1979, for example, deliveries will total 2,708 tons of uranium, and there are agreements for a further 3,920 tons from 1980 to 1985. Contracts are now being negotiated for additional supplies.

Since the quantities of uranium required by individual stations are small physically, transportation presents no problem. However, the processing and manufacturing operations involve several months of lead time, from the production of "yellow cake" (uranium oxide, U_3O_8) at the mine to the delivery of fuel bundles at the stations. A back-up of finished bundles is therefore maintained to ensure operational flexibility and the security of supplies.

Nuclear Fuel Supplies

As we have seen, uranium is the only one of the various fuels that have been discussed that is present in Ontario in quantities large enough to meet a substantial portion of Ontario Hydro's fuel requirements for an extended period. Although there are no foreseeable problems concerning uranium supplies during this century, the predicted world demand for uranium appears to be greatly in excess of the predicted production, in the long term.[13] Sufficient domestic uranium resources and projected production capability are available to meet Ontario's power-system requirements over the estimated operating lives of the Pickering station and the larger Bruce station on Lake Huron, and of a third station that is projected for Darlington, just east of Oshawa. For stations that are likely to come into service after 1990, and for which federal regulations require a commitment of fuel some 12 years prior to their in-service dates, there is a need to develop additional production capability from new uranium finds.

In this situation, and since exploration activity in Canada has been at a relatively low level, Ontario Hydro has deemed it advisable to participate financially in uranium exploration programs with experienced resource companies, such as Shell Canada and Amok Limited, in the hope of stimulating expanded exploration by all interests.[20] New Canadian uranium finds would help to provide security for meeting long-term needs; they would, of course, be subject to lead times of between eight and 12 years.

In the longer term, Canada has two additional potential fissionable fuels to call upon. One is the plutonium-239 that is contained in used fuel elements that are being stored for future use "when the price is right". The other is in the element thorium. This element exists in the form thorium-232 as thorium oxide and, up to now, has been mined chiefly at Elliot Lake, mainly for customers in the U.K. It is not itself fissionable but it is in the category of "fertile" materials, in that, like uranium-238, it absorbs neutrons under certain conditions; then, by a process of natural radioactive decay, it forms uranium-233, which is an excellent fuel.

This nuclear transmutation might be achieved either by surrounding a uranium reactor with a "blanket" of thorium, so that some of the emitted neutrons would be absorbed into the blanket, or by subjecting the thorium oxide to a stream of neutrons produced in some other manner. One way would be to use an

electrical machine to produce the neutron stream, much the way scientists do now on a small scale in laboratories and hospitals. An alternative approach might be to use powerful laser light to bombard pellets composed of a mixture of lithium and tritium compounds, to produce neutrons. Both of these possible methods are being studied.

It is comforting to know that, should thorium be needed, Ontario is once again lucky. The federal Department of Energy, Mines and Resources has estimated conservatively that reserves of relatively cheap thorium exceed 100,000 tons, and that is before any really serious search has been made.[21]

Primary and Secondary Sources

In conclusion, it can be said of the fuels and other primary sources of energy available to Ontario for the generating of electricity, that water has been the star of the past and will continue to make an important contribution. Coal offers the greatest potential for the future among conventional fuels, but it has to be imported, it will be increasingly expensive, it requires a considerable transportation system to ensure regular delivery, its continuing supply is subject to political decision, and it constitutes a considerable and increasing environmental problem. Oil and gas are probably going to be far too expensive. That leaves us with uranium, which is found in Ontario, creates no transportation problems, and is cheap and clean.

Nuclear plant is expensive; capital costs and interest account for about two-thirds of the cost of each delivered unit of electricity and the fuel accounts for one-third. For a coal-fired station, the fuel accounts for about two-thirds of the cost of each delivered unit.

In Table 3, the nuclear station at Pickering is compared with the modern coal-fired station at Lambton.[18]

All of the sources of energy that we have considered so far may be regarded as primary, in that they are naturally-occurring, except that, in the case of residual oil, processing has removed certain constituents that have higher values when used for some other purposes, such as ethylene, gasoline, and various finer oils.

There is one secondary fuel that should be mentioned, and that is hydrogen, which has a high energy content, is as easy to

Table 3. Cost of Electricity (mills per kilowatt-hour)

	Pickering	Lambton
Capital costs	4.60	1.70
Operation and maintenance	1.10	0.96
Fuel	0.98	13.52
Heavy water	0.35	
	7.03	16.18

transport and store as natural gas, and can be as safe as natural gas when handled with respect. One of the great selling points of hydrogen is that it is inexhaustible. It is one of the principal ingredients of water, and can be produced by electrolysis, that is, by passing a direct current through water to provide both hydrogen and the oxygen needed to achieve most efficient combustion.[22] The source of energy for such electrolysis would presumably be nuclear.

Hydrogen can also be produced from coal in a process known as gasification.[23] First the burning coal or coke is raised to red heat by passing air or, better still, oxygen, through it. When air is used, the result is "producer gas", which is 29 per cent carbon monoxide, 11 per cent hydrogen, and the balance mainly nitrogen. The proportion of combustible gas is much higher if oxygen is used. Next, steam is passed through the red-hot coal or coke, until it cools down to the point at which air must be introduced again. The product, when steam is used, is "water gas". Water gas is 49 per cent hydrogen and 41 per cent carbon monoxide.

Hydrogen and oxygen can also be produced by passing steam through a reactor at a very high temperature, when thermochemical dissociation takes place.[24] To achieve this by "brute force" requires temperatures that are at present impractical. However, processes are under development in which water is combined with certain chemical compounds in a specific sequence and the decomposition of the water into hydrogen and oxygen occurs at practical temperatures.[24] The chemicals used would be recycled. The temperatures used, in the 650-700°C range, are still far too high for use in conjunction with most existing nuclear reactors, including the CANDU reactor. However, they are not out of line with what might be achieved in the future with more advanced reactors. Using different reactions and heat sources, the

thermodynamic efficiencies can vary between 14 and 75 per cent.

A further method of producing hydrogen is by "bioconversion", that is, by using algae or bacteria, which, when starved for oxygen, tend to adapt by producing their oxygen from water chemically, releasing hydrogen in the process.[25]

The environmental advantages of a clean fuel like hydrogen, coupled with its ease of transmission, storage, and distribution, encourage continuing research in this area. The main obstacle at present is the cost of production. However, it is possible to contemplate processes that will eventually compete economically with other ways of generating electricity.

The Future

Our immediate future seems to lie with hydraulic power, with coal-burning stations, and with nuclear stations of the CANDU sort: the usefulness of oil and natural gas for the generating of electricity is marginal, due to their cost and to the uncertainty about future supplies. Hydraulic power will constitute a declining percentage of the total. We can expect to draw more heavily on U.S. sources of coal, provided that the cost does not rise disproportionately, and we will soon be drawing substantial coal supplies from western Canada. But for a number of decades the bulk of the additional demand will have to be met by nuclear reactors of the CANDU sort. A new generation of nuclear reactors may be developed in the future that will exploit the qualities of the plutonium we are creating in today's reactors. We can also assume that reactors will be designed to use some of their surplus neutrons to transform thorium-232 into uranium-233, an excellent potential fuel.

The exploitation of the fusion reactions that unite light elements into heavier ones, as in the creation of helium from hydrogen in the sun, are as elusive now as they were in 1955, when the First International Conference on the Peaceful Uses of Atomic Energy was held in Geneva. Most scientists and engineers with any knowledge in the field say that it could be a good 20 years before a working system is developed to the point where it can be used by industry.

Solar energy and wind are unlikely to make any significant mass contribution, but their various merits will increase for individual

applications as the cost of fossil fuels increases. Hydrogen could be an important secondary fuel, several decades from now.

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Bulk Transmission of Electric Power

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Electric power comes to the ultimate user by a complex distribution system that begins with bulk power transmission lines delivering power from generating stations to receiving terminal stations. From the receiving terminal stations, lines radiate to area-supply transformer stations, and from them to the familiar local transformers and thence on to the user.

Ontario Hydro's existing bulk power transmission system is mainly at 230,000 volts (230 kV). Recently constructed lines are mainly at 500 kV and future construction will be predominantly at this voltage. Almost all of these lines are overhead. From the receiving terminal station to the area-supply transformer station go lines that operate at 230 or 115 kV. These lines are mainly overhead but are often put underground in urban areas. From the area transformer stations, power goes out at what are usually called sub-transmission voltages of 44, 28.4, or 14.2 kV, so the distribution network fans out at constantly lower voltages until, finally, it reaches the consumer's electric stove or dryer at 220 volts and his or her lights and other small appliances at 110 volts.

During the last few years, there has been growing public opposition to the construction of new bulk power transmission lines. These form the most visible part of the distribution system, extending from the main generating stations to the major transformer and switching stations. In discussing bulk power transmission techniques, I will deal mainly with lines designed for 500 kV, the voltage at which Ontario Hydro plans to build most of its future bulk power transmission network. Nonetheless, the material should be almost equally valuable to the public in areas

Erecting a new transmission line on a right of way that has been clear-cut through the bush in northern Ontario. (Source: Ontario Hydro)

where the transmission voltage is higher or lower. I will restrict myself to material likely to be useful to anyone wanting to understand, and possibly to influence, Ontario Hydro's plans for bulk power transmission lines.

To anyone totally unfamiliar with the problems of organizing and building a modern power supply network, the first questions may be: "Why do we need to have huge long-distance bulk power transmission lines scattered across the countryside? Why not generate the power close to the point of use and so avoid most of these lines?"

The Need for a Network

In the early days of electrification in Ontario, the main source of

power was the big new hydro-electric plant at Niagara Falls. This plant attracted some industry to the Niagara Falls area, but the main demand for electric power was in the Toronto-Hamilton area. The transmission lines that were built between the generating station at Niagara Falls and the load centres at Toronto and Hamilton were, in their day, among the longest and largest in the world; they were accepted as inevitable because neither Niagara Falls nor Toronto appeared to be portable.

When thermal power plants began to appear, fuelled first by coal, then by oil or gas, and finally by uranium, this simple assumption had to be re-examined. Indeed, some of the early coal-fuelled thermal plants were built close to load centres. The Hearn and Lakeshore plants, for example, originally on the edges of Toronto, are now embedded in the city. Experience showed that, while thermal plants allowed the designer of an electric power system considerable flexibility in locating generating plants in order to optimize transmission line layouts, some important constraints remained:

1. There were increasing objections, because of the smoke nuisance, to the locating of fossil-fuelled plants (especially coal-fuelled) close to the cities. In the case of nuclear plants, the early uncertainty about the risk of accident made it prudent to put the first ones at some distance from major cities, and hence from important load centres.
2. In thermal plants, only 30-40 per cent of the total energy in the fuel appears as electricity. The remaining 60-70 per cent appears as heat, which must finally reach the atmosphere either through cooling towers or, more indirectly, through cooling water. Because the major load centres in Ontario are mainly located on the shores of the Great Lakes where there is an ample supply of cold water for cooling, Ontario's large thermal generating stations have all been located on the shores of one or other of the Great Lakes.
3. Experience showed that there were large and increasing economies that could be realized only by making very large individual generating units and grouping several of these units on one site.

Reliability

By far the most important reasons for having a network are to improve the reliability and reduce the total cost of operating the system.

Even the best power plants have to be shut down regularly for maintenance. Unscheduled shutdowns also occur. If each load centre were supplied by a single, closely adjacent generating plant, few bulk power transmission lines would be needed, but there would be a complete local blackout every time a plant was closed for maintenance. With no bulk transmission system, the only solution would be to duplicate all power plants – as is done in remote areas. Costly as this would be, it would still not guarantee a continuous supply of electricity, because the two plants might have trouble simultaneously (as happens now in remote areas). With a bulk transmission network that can supply any given load centre from not one, or two, but from several generating stations, vastly greater security of the total system can be achieved with a much smaller surplus of generating capacity. Such a system obviously requires that the network of transmission lines be designed to ensure that it will not fail. I will come back to this problem of network reliability, or "security".

In a complex system like that of Ontario Hydro, there are hydro-electric plants and thermal plants using gas, oil, coal, and uranium. Because of the high cost of fossil fuels, hydro-electric and uranium-fuelled plants produce electricity at substantially lower operating costs than the others. In off-peak periods, spectacular savings are to be made by supplying the entire system from these low-cost generating stations. This can only be done with an extensive bulk power transmission network. The magnitude of these savings is illustrated by the following quotation from evidence given by Ontario Hydro to the Solandt Commission (A Public Inquiry into the Transmission of Power) in October 1973, and the differences in cost are larger now: "The third and fourth units at Bruce generating station are expected to be ready for service in April 1977 and April 1978, respectively. These units are fuelled by uranium, which is much cheaper than coal or oil. If the 500 kV line from Bruce to the Toronto-Hamilton area is not available for the delivery of power, there will be an out-of-pocket cost penalty of $250,000 per week in respect of the third unit alone and $800,000 per week in respect of the third and fourth units."

Ontario Hydro pointed out that these figures refer only to the direct cost to Ontario Hydro and do not include the loss to others due to unemployment and the loss of profits if any demand could not be met from other generating stations.

All of these factors taken together constitute an extremely strong case for a bulk power transmission network in a system as large as Ontario Hydro's.

The Advantages of High Voltage

When current flows through a conductor, some of the energy being transmitted is converted into heat. The amount of heat produced is approximately proportional to the square of the current in amperes (twice the current: four times the heat). Since the power transmitted is equal to the product of the voltage multiplied by the amperage, it is obvious that the best way to reduce the loss of power as heat is to transmit power at high voltage and correspondingly low amperage.

Early electrical generating and transmission systems used direct current (DC). It was soon found that this was uneconomical for long distances or large amounts of power because, although direct current could be generated at high voltages, it was often inconvenient if not impossible to use it at these high voltages. Alternating current (AC) can be changed easily and efficiently by means of a transformer from a high voltage with low current, for transmission, to a lower voltage and higher current, for use. Consequently, AC rapidly displaced DC for both the generation and the transmission of power. As the demand for the transmission of larger and larger quantities of bulk power increased, transmission voltages increased, partly to keep line losses down and even more to reduce the size and number of new transmission lines needed to keep pace with local growth. I will discuss the effects of these increasing voltages on transmission lines in more detail later.

All bulk AC transmission systems use three wires instead of two, as is common at lower voltages. This is done because it is convenient to generate AC in a three-phase generator and to transmit it in three phases. For practical purposes it is enough to consider that the three-phase system increases the capacity of each individual line and reduces the problems of insulation, because the voltage between the wires and the ground, or the neutral point in the system, is only half of the voltage between the wires themselves.

The need for a network, or grid, of high-voltage bulk transmission lines has been established. Ideally, the voltages of each section of such a network should match the length and carrying capacity of that section. This is impractical, because all of the equipment for each section of the system would have to be specially constructed. To keep costs within reason, it is necessary to fix on one, or at most two or three, voltages for the entire bulk power transmission

system, making it possible to standardize conductors, towers, insulators, transformers, switch gear, etc. Table 1 gives the number of circuits (three wires per circuit) required to transmit 4,000 MW (megawatt = one million watts) for 100 miles. This capacity and this distance were selected as representative of most segments in Ontario Hydro's network at present and in the foreseeable future. When it is realized that security requirements demand a minimum of two and often three redundant circuits for each link in the network, it becomes clear that, for a 4,000 MW line, 230 kV is too low, because 29 circuits are required, and to duplicate this would raise the number to 58. On the other hand, 765 kV is probably too high, because additional circuits that would not be required to carry the load would have to be built merely to ensure the reliability of the system. Table 1 also shows the tremendous effect of increasing the voltage on the width of the right of way and the total amount of land required.

Table 1. Right-of-way Requirements for 4,000 MW for 100 miles

Voltage (kV)	Capacity per circuit (MW)	Number of circuits	Right of way Width (feet)	Right of way Per mile (acres)
115	30	133	5,025	610
230	140	29	1,200	145
500	2,200	2	200	25
765	4,300	1	135	15

Source: "HV and EHV Transmission Planning" by Walter Scott, Commonwealth Associates Inc., in *Energy International*, July 1972

The differences in cost for the same capacity are also spectacular. Table 2 shows the relevant cost per mile of one two-circuit 500 kV line and of both four and seven double-circuit (8-14 circuits) 230 kV lines, on the assumption that, under varying circumstances, it may take from four to seven 230 kV lines to equal the power-transmitting capability of a single 500 kV line. The 230 kV lines used in Ontario Hydro's cost calculations in Table 2 have a substantially higher capacity per circuit than those used for comparative purposes in Table 1.

Table 2. Per-mile Costs

Number of lines	Per-mile cost ($)	Right-of-way width (feet)
one 2-circuit 500 kV	600,000	250
four 2-circuit 230 kV	1,200,000	530
seven 2-circuit 230 kV	2,100,000	950

(Per-mile costs do not include the cost of property or of legal service.)

The data in Table 1 and Table 2 support Ontario Hydro's selection of 500 kV for its bulk power transmission system. The present technical opinion is that, should the system continue to grow as predicted, a higher voltage will have to be introduced in the bulk power transmission system about 1995 and that the voltage then selected will probably be above 1,000 kV and might be direct current.

Designing a Line

A transmission line consists of conductors suspended in air with enough separation that the air will act as an effective insulator between them. At 500 kV the power is always transmitted by a three-phase system. Each phase is carried on a separate conductor, so that a complete circuit consists of three main conductors. Each of the main conductors is made up of four sub-conductors evenly spaced around a circle 28 inches in diameter. Such an arrangement minimizes losses as well as interference with local radio and television reception. Each sub-conductor is just under an inch in diameter and consists of a steel core, for strength, surrounded by aluminum wires through which the electricity flows.

The spacing between the main conductors is such that, even under the worst conditions of wind and ice-loading, the conductors cannot swing close enough to cause the air insulation between them, or between them and the tower, to fail. Since the conductors are insulated from one another by air, they must be suspended in the air by a tower and connected to the tower by insulators strong

enough to carry their weight. The length of the insulators must be sufficient to ensure that current cannot pass across them from the conductor to the tower, even under very bad atmospheric conditions.

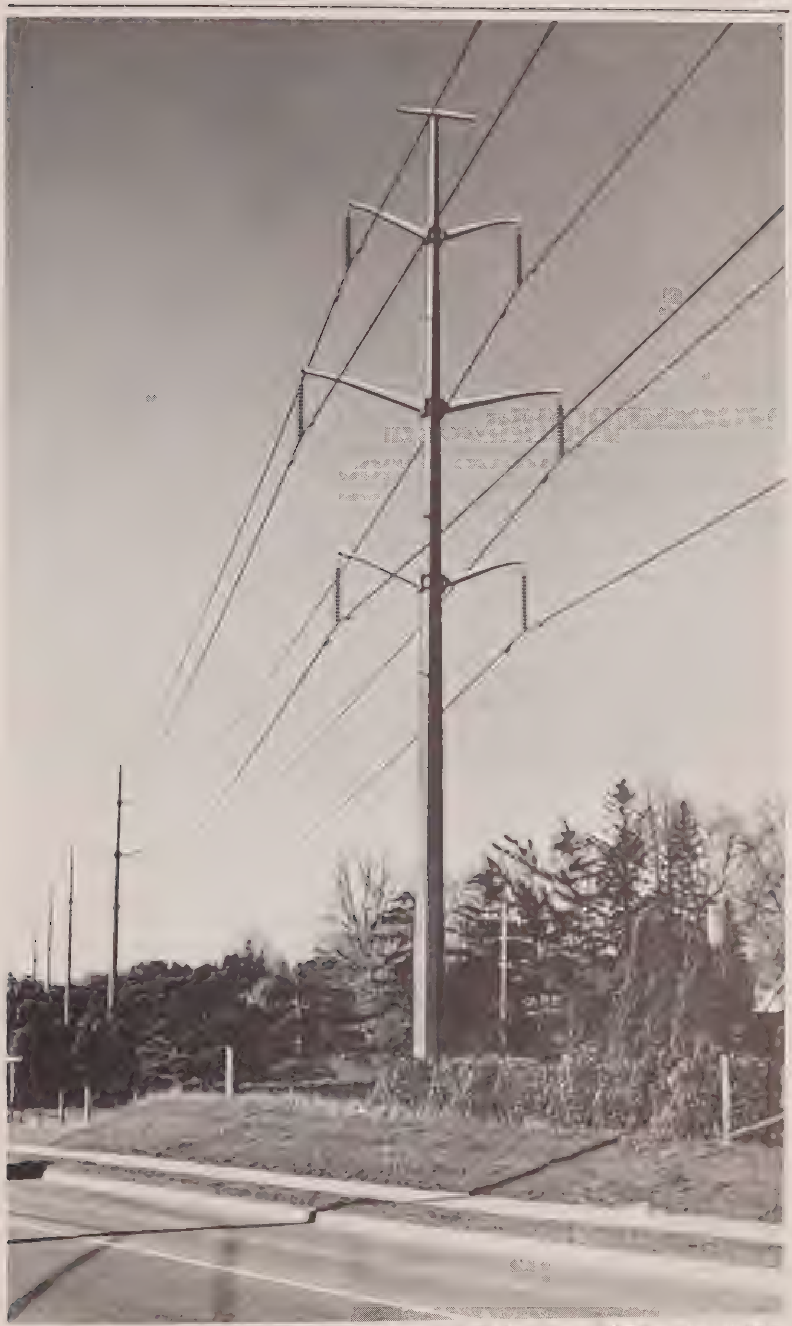
In addition to the main conductors, the towers carry two sky wires at the top. These are not insulated from the tower and serve to carry lightning and fault currents.

Where the nature of the soil is such that the towers cannot be well grounded by an ordinary ground electrode, a "counterpoise" is installed. This consists of two wires buried 8-18 inches deep, one on each side of the towers, running along the right of way.

Once conductor spacings have been determined and the length of insulator required to support the conductors calculated, it is possible to begin designing towers that will hold the conductors at the desired spacing.

There is no doubt that the most widely resented feature of bulk power transmission lines is their appearance. It follows that every effort must be made to make the towers small and inconspicuous. Unfortunately there is no practicable way to get along without the towers, so the various trade-offs that are possible must be considered. The first and probably most important trade-off is in height. Where only a single three-wire circuit is used, the tower may be kept low by putting the three wires in a horizontal line, or it may be kept narrow by putting them one above the other, in which case it will be taller. More often, there are two three-wire circuits, so then there is the option of using one or two rows of towers. Here again, the choice is between width and height. The point is illustrated in Figure 1. In public hearings and opinion surveys in Ontario, opinion has been almost unanimously in favour of the double-circuit tower in order to minimize the width of the right of way, even at the expense of increased height.

In addition to merely holding up the wires, the towers must be strong enough to support the heaviest expected combination of ice load and wind load. It is obviously not possible to make towers that will resist any conceivable load, so they are usually designed to withstand a storm of some specified degree of severity. Electric power companies differ widely in their practice in this respect. Ontario Hydro specifies that its towers should not fail under the worst storm conditions that can be expected to recur no more often than once in 50 years (the "50-year return storm") and must withstand a 20-30 year return storm without permanent distortion of components. As a result, structural failures of towers in the Ontario Hydro system are quite infrequent.



A 230 kV transmission line through Lorne Park, west of Toronto, using steel pole towers instead of the more familiar lattice-type towers. (Source: Ontario Hydro)

Another important aspect in the design of bulk power transmission lines is the spacing between towers, along the line of the wires and between rows of towers occupying the same right of way. Longitudinal clearance is determined by the nature of the terrain, the required ground clearance, and the acceptable tension on the wires. Ontario Hydro's policy for 500 kV lines is to require that the lowest conductor at its maximum sag be 40 feet above the ground and that no trees come within 15 feet of the conductor. To achieve this, Ontario Hydro normally uses double-circuit towers about 160 feet high at intervals of about 900 feet. Where the line crosses a valley, this spacing may be increased and where it goes over the crest of a hill the towers may have to be put closer together. If for any reason it is necessary to use shorter towers, they are put closer together or tension on the wires is increased in order to maintain the ground clearance. So there is a good deal of flexibility in the spacing of towers. This is fortunate because it makes it possible to adjust the locations of individual towers – for example, to avoid particularly awkward spots on farms.

The minimum spacing between adjacent conductors is determined by electrical considerations. In practice, this minimum is usually exceeded because of other requirements. Ontario Hydro now uses a 250-foot right of way for a double-circuit, 500 kV line. Since the main cross-arm of the tower is about 85 feet wide, the clearance on either side of the right of way is about 82 feet. For two double-circuit lines, the spacing between lines is 175 feet (90 feet between cross-arms) which means a total width of 425 feet for the right of way. Where security is of special importance, the spacing is increased to 230 feet. This means that, if one tower fails and falls towards the adjacent line, the line is far enough away that it is not brought down by the wreckage of the falling tower.

Locating the Line

The need for and general characteristics of bulk power transmission lines have been described. The next step is to suggest how the lines can be fitted into desirable patterns of land use under a variety of conditions.

Since a bulk power transmission line is a dominant feature of the landscape, it is obviously an important element in land-use planning and control in any circumstances. The characteristics of

high-voltage lines that are important from a land-use point of view are probably best understood by comparing them with the characteristics of other linear systems that are now competing for land. At present, the only other linear systems that are being built in southern Ontario are expressways and pipelines. Other high-speed ground transportation systems on their own rights of way will almost certainly be added to this list in the not-too-distant future.

Generally, bulk power transmission lines often need a wider right of way than the others. However, unlike expressways and railways, transmission lines create no physical barrier separating the land on either side of the right of way. Except at the actual locations of the towers, all normal traffic – whether on roads, on farms, in woods, or in open country – can pass back and forth under the lines. In addition, Ontario Hydro not only permits but encourages many secondary uses of the rights of way, including farming, fruit growing, and a variety of recreational uses. In some other countries, including England, buildings (including homes) are permitted under transmission lines, so long as certain height restrictions are observed.

In fact, transmission lines appear to compare quite favourably with other linear land uses, except in their high visibility, which weighs heavily against them. The other linear land uses with which the transmission line is compared are comparatively low on the ground, so they are only occasionally visible from a distance. In contrast, the 160-foot towers of a 500 kV double-circuit transmission line are all too clearly visible.

Many people still have a mental picture of a transmission line in a clear-cut swath crossing the countryside, with all trees and even large shrubs removed along a broad right of way. Ontario Hydro practises clear-cutting in the north, where there are few inhabitants and the vegetation is of relatively little value either commercially or to wildlife, but in all other areas it practises extremely selective cutting. Branches of trees are not allowed to come within 15 feet of the conductors at their lowest points. This means that, in the part of a right of way that is directly under the lowest point of the conductors, the height of trees is limited to 25 feet. Towards the edges of the right of way and close to the towers, higher trees are permitted to remain. In general, trees that can be pruned without great damage are pruned, whereas older trees whose only branches are high ones and which would therefore be killed by pruning, are felled. Where it is necessary to clear vegetation from

the right of way, new vegetation is planted to replace it, selected from a range of native shrubs and trees that are unlikely to grow too tall. In areas where there has been considerable removal of trees, Ontario Hydro is willing to plant additional trees, even off the right of way, to restore the local balance between treed and untreed areas.

In addition to the selective cutting of the right of way, access to each tower site is required during construction. In many settled areas, this can be done without building an access road along the right of way. The conductors are normally strung by a technique called "tension stringing". This requires heavy equipment only at one tower site in every five miles or so, and, if access to the other tower sites can be obtained from adjacent public roads and soil conditions are such that no counterpoise is needed, only the foresters require access to the right of way between tower sites.

Ontario Hydro has perfected techniques for minimizing the disturbance of soil and vegetation at tower sites. The disturbance naturally varies with the nature of the terrain and the type of foundation required. In addition to striving to limit environmental disturbance during construction, Ontario Hydro undertakes a careful restoration of disturbed areas around tower sites and on access roads, as the final part of each construction program.

Electrostatic and Electromagnetic Effects

The operation of transmission lines produces electric and magnetic fields in the space around the lines. Under certain conditions, a visible "corona", or glow, is generated on the lines, especially where they are attached to insulators. Corona can produce audible noise, radio and television interference near the line, and traces of ozone adjacent to the conductors. Through careful control of the designs of transmission lines, corona has been eliminated under good atmospheric conditions and is only slight in foul weather. Experience has shown that the noise and radio and television interference from a 500 kV power line are negligible outside the right of way. In fact, the right-of-way widths used by Ontario Hydro have been selected to ensure protection of the public against these effects.

Both electromagnetic and electrostatic induction can cause currents and voltages in metallic objects under a power line that are strong enough to give a person a noticeable sensation. These effects have never been known to be more than unpleasant, and they can be eliminated by the proper grounding of metallic objects and the appropriate designing of installations that are subject to electromagnetic induction.

There have been some reports recently of biological effects of high-voltage electric fields, especially in the U.S.S.R. All of these reports appear to be based on weak evidence. The most careful experimental research and continuing observation of line maintenance crews in western Europe and North America have failed to provide any significant evidence of harmful biological effects, even among men working directly on 765 kV lines and sub-stations. In spite of this good experience, Ontario Hydro and other utilities continue to watch for possible problems and to sponsor independent studies.

The fear is often expressed that high-voltage towers attract lightning and are a hazard to those near them. All tall structures attract lightning, but, since transmission line towers are carefully grounded, they actually provide some shielding to the ground below them and consequently are safer than most other man-made structures, which as a rule are not well grounded.

Ozone is a naturally occurring form of oxygen, and it has a characteristic odour. It is toxic to man and can in some circumstances be quite harmful. Ozone has recently been detected in significant concentrations in urban areas. Since it can be produced by electrical discharges, its production by high-voltage transmission lines has been carefully studied. The conclusion is that high-voltage transmission lines make no significant addition to the amount of ozone present in the atmosphere. The main source of ozone in urban areas appears to be the combustion of fuel.

Tower Design

Now I would like to bring together, briefly, the various factors that affect the appearance of power transmission lines. Some of them have been discussed elsewhere from other points of view. The first and most important factor is the height of the towers. This, as I

have explained, depends on the number of circuits on the tower, the arrangement of the wires in the circuits, and the spacing between towers. The height of the towers can be reduced, but only by using more rows of towers or putting the towers in each row closer together.

There are many tower designs to choose from. The three most common are shown in Figure 1. The first is a guyed lattice tower of the type Ontario Hydro used on its first 500 kV line from Moose River to Toronto in 1965. This type of tower is both the lightest and the shortest, and it is therefore relatively inconspicuous. It occupies very little ground area, but each tower creates five obstructions on the ground, one for its single foot and the others for the four guy wires.

The second is the self-supporting lattice tower, the most common type of high-voltage transmission tower. Shown is one of Ontario Hydro's most recent designs for a 500 kV double-circuit tower. About 165 feet high, this tower contains more steel than a guyed tower but a great deal less than a single-shaft tower.

In recent years, there have been many new tower designs of "improved appearance". The most common of these consists either of a single shaft or of two shafts side by side, giving a somewhat modified H shape. The third sketch in Figure 1 shows a single-shaft tower recently installed by Ontario Hydro. Many observers prefer the appearance of the single-shaft tower. Its main disadvantages are that it uses about twice as much steel as a lattice tower, costs about twice as much to make and erect, and creates a vastly larger disturbance at the site of erection because of the large foundation it requires.

Another important aesthetic consideration is whether there should be one or several lines in a right of way. At public hearings in Ontario, there was almost unanimous agreement that, where more than one line is required in an area, all should be put in a single right of way. This is exactly contrary to the practice in Great Britain, where each line occupies a separate right of way, except where this is not feasible, as in the approaches to switching or generating stations, where the lines must converge. In France, I have seen 14 lines abreast in one right of way.

Transmission line engineers like to build in straight lines wherever possible. Critics sometimes feel that this is done merely to simplify the engineers' task. In fact, it is done to avoid the substantial extra cost of putting angles in the line. The ordinary transmission tower that is used in a straight line is called a

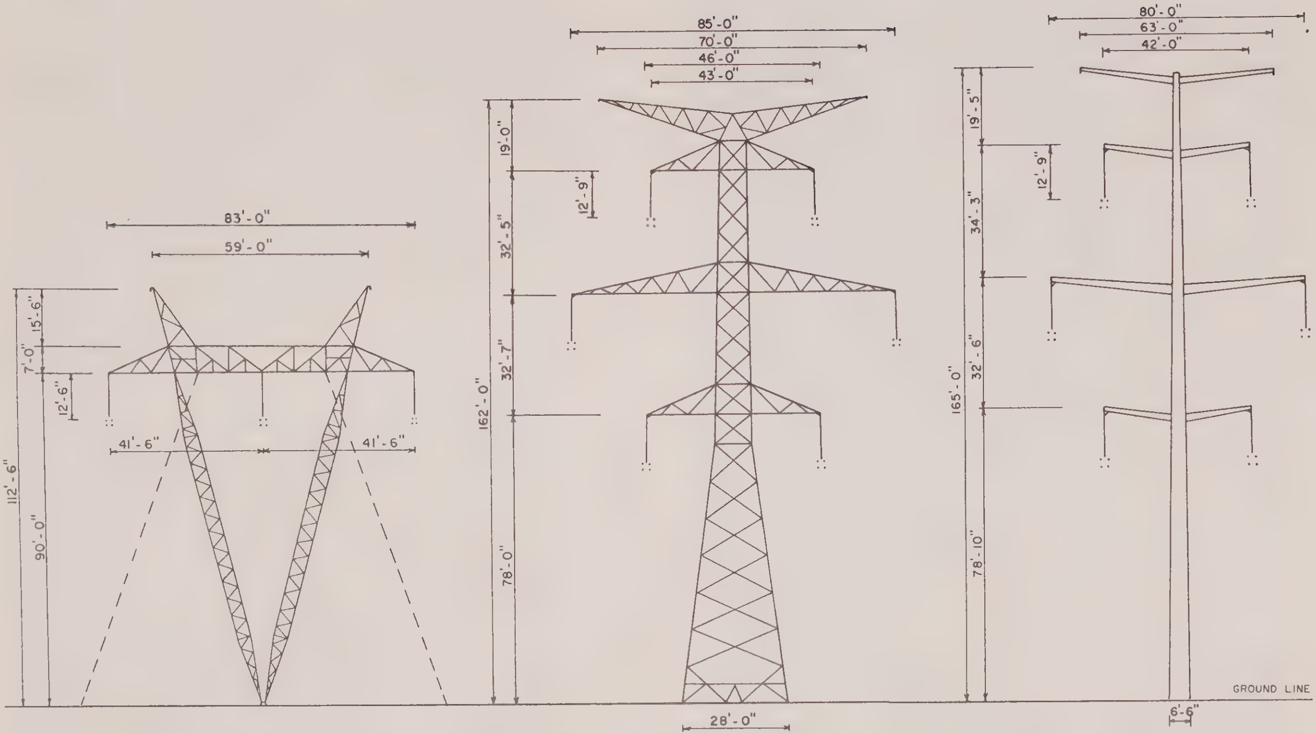


Figure 1. Three types of towers used in Ontario for 500 kV transmission lines: (left to right) guyed single-circuit tower with conductors arranged horizontally, two-circuit tower of lattice design, and two-circuit steel tower of single-shaft design. (Source: Ontario Hydro)

suspension tower and is designed to support the weight of the lines as well as any side loads due to wind. When a bend occurs in the line, new side loads are introduced. This requires a stronger and heavier, or laterally guyed, tower. Table 3 shows the weights and costs of suspension and heavy-angle unguyed towers.

Table 3. Weights and Costs of Towers (500 kV, two circuits)

	Weight (structure only) (lbs)	Cost of structure (installed) ($)
Lattice structures		
Suspension	40,400	55,000
Heavy angle	152,000	250,000
Pole Structures		
Suspension	98,000	120,000
Heavy angle	230,000	339,000

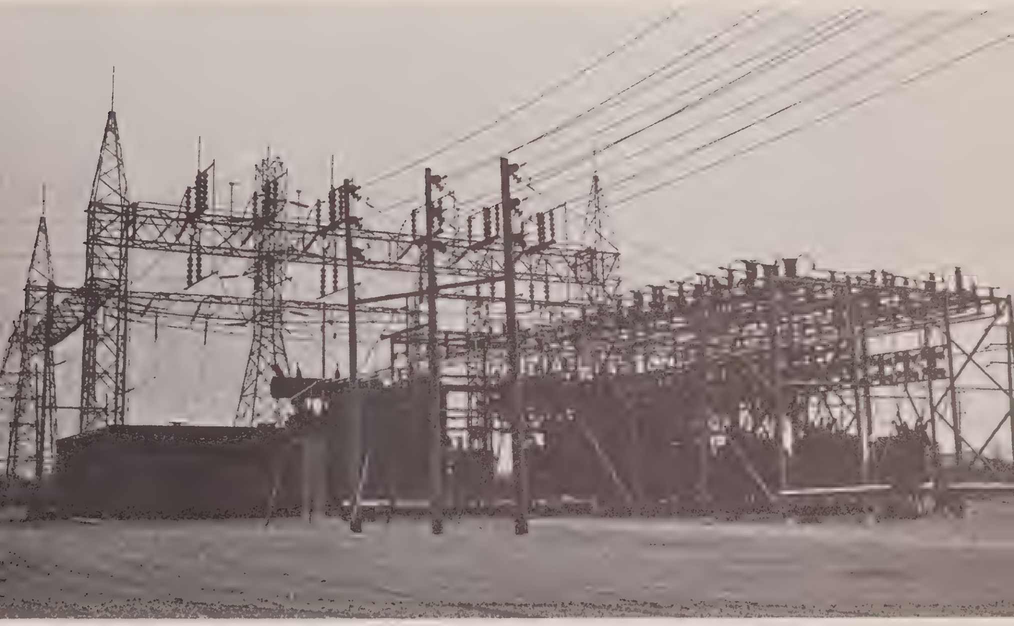
Source: Ontario Hydro

Transformer and Switching Stations

Transformer and switching stations serve two essential functions in a power system. They interconnect transmission lines, transformers, and sub-transmission lines, and they change voltages from one transmission level to another – or to a sub-transmission level. At the end of 1974, transformer and switching stations represented about 13 per cent of Ontario Hydro's capital investment. Transformer and switching stations come in many sizes, but what follows is concerned with the receiving terminal station located at the end of a major 500 kV bulk power transmission line.

It is impossible to describe here in detail all of the equipment that is contained in such a terminal station, but here is a brief outline of the principal items:

Transformers. A typical modern transformer designed to change the voltage from 500 kV to 230 kV weighs about 350 tons. Since they are usually shipped from the factory in one piece, these have an important



A transformer station of conventional design at Agincourt (above) and a newer station of low-profile design at Lorne Park (below). (Source: Ontario Hydro)

influence on the location of transformer stations. They are usually transported by rail and can be moved on gravel roads but are prohibited on virtually all surfaced roads. When in operation, transformers are relatively noisy, so they are installed in acoustic enclosures to keep the noise at the boundary of the station site at an acceptable level.

Circuit-breakers. These are the devices that are used for closing and opening the power circuits in an emergency. They differ from load interrupters in that they are designed to be capable of interrupting fault currents that may be 16 to 20 times the normal maximum current in the circuit. The air-blast circuit-breaker is the one most commonly used at 500 kV. The arc that occurs when the circuit is opened is extinguished by a blast of compressed air. This results in a sharp report that is usually audible outside the station. It occurs quite rarely. Similar circuit-breakers using sulphur hexafluoride gas (SF_6) instead of air are rapidly replacing air-blast circuit-breakers at high voltages and will be discussed below.

Switches. Switches are of two types: isolating switches, used to disconnect from the system a piece of equipment or line that is not in use, and load-break switches, which can be safely opened or closed under full load but will not withstand fault currents, as circuit-breakers do.

These three elements and the others mentioned below are interconnected by large conductors, called buses. These are either large cables or rigid aluminum or copper tubes.

In addition to the main elements described above, major transformer and switching stations may also have a variety of devices such as capacitors; shunt reactors and synchronized condensers, required for voltage regulation of the system; lightning arresters, spark gaps, and grounding systems for lightning protection; and an auxiliary power supply to operate the station services during a power failure.

Main transformer and switching stations are also the nodes in the complex control and protective relay installation that is used both to control and to protect the system as a whole. In the Ontario Hydro system, the control functions have become so complex that a computer-assisted supervisory control and data acquisition system is now being installed. This is expected to permit the control of many more stations from one control centre and to achieve both better control and better protection of the system

Three types of transformer and switching stations are available for use at 500 kV. The first is the so-called three-level terminal,

using strain buses (stranded cable conductors of copper or aluminum) suspended between steel structures supported and insulated from the structure by porcelain insulators. The second is the two-level low-profile station in which rigid buses of copper or aluminum tubes are supported on rigid porcelain insulators mounted on steel structures. The third is the gas-insulated station in which sulphur hexafluoride gas is used instead of air as the main insulating medium. A typical high-profile station is 96 feet high and occupies 255 acres; a low-profile station of the same capacity is 50 feet high and occupies 380 acres; and a gas-insulated station occupies about 45 acres.

The large size of air-insulated transformer stations is primarily due to the need for wide separation between exposed high-voltage components, and between the components and the ground. The substantial over-all reduction in size that was described above is achieved by enclosing switch gear and buses in gas-filled metal ducts that form safety barriers. At 500 kV, these ducts need be only 24 inches in diameter. This compares with a clearance approaching 25 feet that is required around an open bus at 500 kV.

There are more than 100 gas-insulated stations in service in Europe, some of which have been operating since 1967. None is as large as those planned by Ontario Hydro. However, the experience in Europe has been so good and the advantages for Ontario Hydro are so great that two have been ordered for installation at the new stations at Clareville and Milton, near Toronto. Because the sulphur hexafluoride stations are small, it is possible to enclose them in buildings that will make erection, operation, and maintenance quite independent of the weather. The stations are being designed so that most of the 500 kV transmission circuits will terminate directly on the switch-gear building, thus avoiding the heavy anchor-line structures that would otherwise be required. Although the cost of the individual components of gas-insulated switch gear is about twice the cost of similar air-insulated equipment, it is expected that the total cost of a completely installed gas-insulated station may be less than that of an air-insulated station. Operating costs should certainly be less.

The gas-insulated switching stations are so much smaller than the older ones that it will be relatively easy to find locations for them that are not excessively prominent and that can be screened by trees and mounding. Such stations will have no adverse effects on neighbourhoods. They will not produce any significant noise or smell, nor will they interfere with radio or television reception. Ozone production will be negligible.

Two chemicals used in such stations require comment. Sulphur hexafluoride, used to insulate the station, is a colourless, odourless, non-flammable, inert gas with highly desirable electrical properties. It is non-toxic but can, of course, cause suffocation by excluding oxygen just as nitrogen or carbon dioxide can. The likelihood of this occurring is remote, since the gas in the system is contained in a large number of small, individual, sealed compartments. Even if a few of them were ruptured, the resulting concentration of gas in the building would be low. Sulphur hexafluoride gas can be decomposed by exposure to an electric arc. Provision is made for the absorption of these decomposition products within the gas-tight chambers of the system.

Both outdoor capacitor banks and indoor transformers often use, as an insulant, a synthetic, non-flammable liquid of a non-biodegradable polychlorinated biphenyl (PCB) compound known commercially as askarel. It is now well established that the PCBs are both long-lasting and highly toxic to many organisms and should not be released. In capacitors and transformers, PCB is contained in a closed system that is carefully designed and built to prevent accidental leakage. In addition, provision is made to catch any leakage, should it occur, in order to be as certain as possible that the environment is completely protected from this liquid. The search for a less toxic substitute is being actively pursued.

Effects of the Line on the Landscape

In wilderness areas used for recreation, the principal ill effect of power lines is the intrusion of a highly visible, "civilized" element into an otherwise natural landscape. In forested areas, the lines are not visible to hikers or canoeists except when they are on or close to a right of way. In heavily forested areas, the selective cutting of a right of way may substantially benefit wildlife by providing increased browse for deer and a more favourable environment for small animals and birds. In spite of this, there is a strong feeling among environmentalists that transmission lines should be kept out of wilderness or conservation areas.

Where lines are built over hilly or sandy country, great care must be taken to prevent erosion. This can be unsightly because of the scarring of the landscape, and – much more important – run-off may pollute nearby streams seriously enough to make them

A 230 kV transmission line through farmland in southern Ontario (Source: Ontario Hydro)

uninhabitable for game fish. Careful control of the selection of tower sites and rapid re-covering of exposed soil with vegetation can largely eliminate this hazard.

In the days of clear-cutting of rights of way, small streams were exposed and became too warm for game fish. Sometimes the extensive removal of vegetation led to excessively rapid run-off and the drying up of small streams, swamps, and ponds in summer. Where selective cutting is practised and ground cover with suitable vegetation is maintained, these hazards do not arise.

In southern Ontario, there has been a vigorous reaction from the agricultural community against the construction of bulk power

transmission lines across good farmland. The disadvantages cited include the compaction of carefully tilled soil and the destruction of tile drains by heavy vehicles during construction; the destruction of fences and crops by access roads; the residual difficulties of cultivating, seeding, and harvesting around the bases of towers; the difficulty of controlling weeds under tower bases; the psychological effect of a line "dividing" a farm, even though cultivation under the wires can continue uninterrupted; and, finally, the visual and psychological intrusion of the line on the farm. In addition, there are a few much more specific special objections. For example, lines over a field make it hazardous to use gun-type irrigation equipment or to use aircraft for spraying crops.

These problems are real ones, but extensive experience has shown that they do not present serious impediments to active and effective farming; they merely add some cost and inconvenience. Ontario Hydro attempts to recognize these factors in its payments to farmers.

In addition to these specific concerns, many farmers, especially in southern Ontario, have expressed grave concern over the serious loss to the spreading cities of high-class agricultural land in areas with favourable climate, pointing to the huge acreage occupied by transmission line rights of way. This is an untenable argument, because the area of land taken out of cultivation by two lines of 500 kV two-circuit towers built through agricultural land is only about one acre per mile of right of way. In addition, the construction of a transmission line guarantees that the land will not be used for industrial or residential buildings. It therefore sharply limits the alternative uses to which the land can be put in the future. From the point of view of the farmer owning land in a suburban area, the most serious objection to construction of a transmission line is that it permanently removes his option of selling the land under the line for development, should he wish to do so.

In most of southern Ontario, people have been spreading out from the cities to build homes in the country. Many of them do some farming or plant trees on their land, but their primary objective is to escape from the city. It is understandable that these people will strongly oppose the construction of a transmission line, whether it is on their property or merely within their view. Although the reasons they give are quite often complex, in the final analysis what they object to is the intrusion of the civilization from which they are trying to insulate themselves.

Apart from the visual intrusion, a bulk power transmission line is quite a good neighbour in a residential area. It produces no noise or pollution, as does a highway, and it provides a permanent open space that can be developed for parks, recreation, or gardening. This assessment of the power transmission line is borne out by many real estate agents who report that, in heavily built-up and congested residential areas, houses alongside a transmission line right of way are preferred to others in the district. As residential crowding diminishes, the advantages of open space grow less and the visual intrusion seems more important, until the attitude of the rural-estate dweller is reached.

In fully developed heavy and medium industrial areas, the lattice towers of bulk power transmission lines seem to be quite at home, and few object to them. In light industrial and commercial areas, the single-shaft towers blend better with the landscape, and seem to be preferred by most people.

Choosing a Route

The first step in selecting a route for a bulk power transmission line is to determine its origin and destination. In nearly every case, the line will orginate at a major generating station and end at a receiving terminal station adjacent to a major load centre.

The next step is to search the area between the two points for all possible routes that are sufficiently direct to justify consideration. If there is any doubt about how big the study area should be, it should be enlarged rather than made smaller. The time and cost that are added by enlarging the study area are comparatively small, and opposition may be intense if any route that appeals to a significant part of the public is omitted from consideration.

The third step is to make a detailed inventory of all of the environmental factors to be considered. The list of elements that *must* be considered is long, and the list of elements that *could* be considered is many times longer. The first list begins with such obvious features of the natural terrain as lakes, rivers, and swamps, the contours of the land, with a special emphasis on steep areas, and the nature of the vegetative cover. In most areas where a bulk power transmission line is to be located, man-made features are dominant. These include roads, railways, pipelines, other power lines, and built-up areas, whether industrial or residential.

High on the list of items to be studied are special features that will probably have to be avoided by the route, such as historic buildings, graveyards, and recreational areas.

It is seldom necessary to study land use in heavily built-up areas, since the cost and difficulty of running a bulk transmission line through such areas is usually prohibitive. In less densely settled areas and in good farmland, it is necessary to do a detailed inventory of land use and of the location of homes and farm buildings.

The usual practice is to record this data on a series of maps. For example, in a study of a route from Nanticoke to Pickering, nine maps were used. Map 1 showed all buildings and structures in the area and sub-divided the agricultural land into three classes. Map 2 showed parks, conservation authority lands, golf courses, recreation sites, trails, and cemeteries. Map 3 showed linear land uses, such as highways, expressways, gas and oil pipelines, railroads, and Ontario Hydro rights of way. Map 4 showed future land uses that were included in existing official municipal plans. Map 5 showed natural resources, including woodlands, forests, and agricultural land capability. Map 6 showed critical natural features, such as flood plains, steep slopes, lakes, rivers, and streams. Map 7 showed natural features of the region that were primarily of scenic interest. Map 8 showed land elevation, and Map 9 included any sites there were reported by interested citizens as being important and that had not been included in any of the other maps. It is obvious that the data could have been subdivided further and put on a greater number of maps.

When the inventory is complete and the data are suitably displayed on maps or otherwise, the next step is to select the criteria by which the route will be selected. At this point, opinions begin to diverge widely. For example, some naturalists feel that bulk power transmission lines are compatible with farming and can be routed through agricultural areas. On the other hand, many farmers feel that non-farmable areas such as forests and swamps are ideal for a power line. Some feel that lines should be put in or close to heavily built-up areas, since nature has already been largely excluded from these areas. Those who live in the built-up areas often feel that they already have more than their share of Man's works and that bulk power transmission lines should be kept out of their sight.

If the public discussions on the selection of a power line route are analysed, it is found that most of the argument centres explicitly or

implicitly around the selection of these criteria. Once the criteria have been agreed upon, an experienced expert who was involved in the inventory and mapping process and is familiar with the study area can probably choose an excellent route in a very short time by a simple study of the inventory data, cross-comparison of alternative routes, and on-the-ground inspection of the difficult areas. He may produce a good plan, but it will be very difficult for him to justify his selection, even to another expert, much less to the public. Many techniques have been evolved for making reasonably objective use of the inventory material and the selection criteria to choose a route. One of the best of these, and the most easily understood, is the overlay mapping technique.

In this method, each of the variables that has been agreed upon as being important is transferred from the map to a transparent map overlay, using different shades of grey to indicate the degrees of undesirability. For example, if it has been agreed that lines will not go through built-up areas, then a map is prepared in which the heavily built-up areas are solid black and areas with no human habitation are clear. Other areas are various shades of grey indicating the density of habitation. When all of the factors to be considered have been transferred to overlays, the overlays are placed over the base map of the area. The areas with least shading will be those most suitable for the construction of a power line. The next stage, then, is to consider these areas and to select from among them a series of corridors within which specific routes can be plotted.

Another technique starts with feeding the inventory data into a computer, either on punch cards or on magnetic tape. The computer can then be given the criteria for the selection of a route and it will proceed to print maps that are similar to the overlay sheets. Computer techniques have proved quite satisfactory for making a quick general study of a large area but have not yet been perfected to the point where they can do a good job of plotting specific routes. However, improvements are proceeding rapidly, and it seems probable that computer methods will ultimately be widely used.

One of the main disadvantages of existing computer methods is that they are not at all easy to understand, and members of the public can get the feeling that the computer is being used to confuse them and to hide the real issues. On the other hand, the map overlay technique, once seen, is immediately understood, and each person can form his own opinion of the validity of the

selection that has been made by the experts.

Future Improvements

The possibilities for improving bulk power transmission range all the way from a steady refinement of existing techniques to a complete abandonment of electricity as a means for distributing energy. The important evolutionary improvements that are already foreseeable include various ways of making power lines smaller for the same capacity. For example, Ontario Hydro already has experimental lines in service using new and shorter insulators and improved methods for controlling "galloping" in the conductors, so that both the height of towers and the width of rights of way can be reduced. "Galloping" is the cyclic motion of wires that can be caused by wind; it can so reduce the distance between wires as to cause electrical failures.

The possibilities of ultra-high-voltage transmission at voltages above 1,000 kV have already been mentioned. Present towers for these voltages are huge, but foreseeable improvements may reduce them to a more acceptable size.

Direct current lines, whether overhead or underground, are smaller and cheaper than alternating current lines of similar capacity. In the past, the added cost and complexity of equipment necessary to convert from AC at the generators to DC for the transmission lines and back to AC for local use have been considerable. Recent developments in solid-state physics have resulted in cheaper and more reliable conversion equipment. The recently opened DC line from Nelson River to Winnipeg and the New Brunswick-Quebec DC interconnection are keeping Canada in the forefront of these developments. Ontario Hydro is watching the possibilities of direct current closely, both for underground cables and for higher-voltage overhead bulk transmission lines.

Nearly everyone would like to see bulk power transmission lines put underground. The feasibility of doing this is being reviewed continuously by Ontario Hydro and other utilities all over the world. While large-capacity, high-voltage underground cables are already being used to carry power from outlying transformer stations into major cities and have been installed in a few places in rural areas on purely aesthetic grounds, they have had limited use because they are rarely less than 10 times as costly as comparable

Interconnection towers at the R. H. Saunders-St. Lawrence generating station, Cornwall, which form part of the link between the New York and Ontario power grids. (Source: Ontario Hydro)

arrived at is strongly influenced, not only by narrowly technological and economic considerations, but also by social and economic forces and vested interests, and by cultural values.

The side-effects of the use of electrical power today include:

1. the potential hazards of the production technology, e.g., in nuclear generators;
2. pollution caused by the production process;
3. the allocation of land for, and the environmental impact of, transmission lines;
4. the enormous investment required to expand the electrical system; and
5. the inhibiting effect of technology and social planning on local innovation and choice, and public participation.

The Side-effects of Energy Systems

Our society is continually being forced to compromise between these factors. The institutional processes by which we make the choices, and the actual choices we make, are both powerful reflections of the kind of life we aspire to.

At one time, the only factors seriously considered in the decision-making process were abundance of supply, cost of production, and technological usefulness. Decision-making in energy matters was done largely by individual private companies, each pursuing its own interest in the marketplace. Ontario Hydro, although it is a public utility pursuing a public mandate, has apparently operated in this fashion in the past. But times are changing, and today the side-effects of energy policies are getting more and more attention from the public.

Any analysis of electrical power planning, especially with respect to the side-effects, must begin with consideration of the total energy system. This is so because some of the most important trade-offs in the working out of energy policy are trade-offs among forms of energy. While it may suffice, for practical, day-to-day purposes, to consider electrical energy separately from the total pattern of energy production and use in our society, when it comes to long-term energy policy the total energy flow must be taken into account.

Indeed, the increasing importance of the side-effects of our energy system brings the following lesson home to us: When

long-term social policy is at issue, it is wisest to resist any inclination to separate energy from the rest of the fabric of society or to treat it as an independent commodity. We only need to recall the way almost all of our other social decisions ultimately affect the pattern of our use of energy to realize that policy-making for energy is intimately bound up with every other important feature of our society.

Consider, for example, how the increasing height of buildings in the centres of our cities leads to ever-greater consumption of electricity for heating, air-conditioning, and elevators – or the way the interior design of those buildings depends increasingly on artificial lighting. And add to this the way the ready availability of all these fixtures and appliances leads to an increasing demand for them, by encouraging habits that take them for granted.

My conclusion from these considerations is that, if we want to achieve a certain kind and quality of life, then we must plan for it in an all-round way, adapting our energy system and technologies to that end. The increasingly important side-effects of energy systems confront us with these twin challenges: (a) how to devise and set in motion the institutional means to plan effectively for our energy needs, and (b) how at the same time to avoid both financial bankruptcy and social stagnation – the alienation and loss of personal freedom that so often accompany the rise of powerful, centralized bureaucracies (in this case, the energy bureaucracies, both public and private).

I also see in this situation the same challenging and threatening elements that I see in all of our socio-economic problems: depletion of resources, pollution, urban blight, technological alienation, poverty – all pushing us towards systematic economic and social integration and away from expansive, individualistic culture.

Two Contrasting Scenarios

Let us imagine two very different responses our society might make to these challenges. At one extreme might be a policy of retaining the existing, strongly individualistic, competitive market system, in which the costs of economic competition, including those of all of the side-effects we have discussed, are allowed to accumulate as they may. Many people believe that in that direction lies a worsening of our social condition. It is worth noting here that

ever the tremendous importance of a relatively cheap and completely dependable flow of energy into our homes, offices, and factories. Ontario Hydro cannot afford to scrap any substantial part of its existing system, nor can it take chances on introducing untried innovations into its operating system. The research, development, and testing that are required to produce an innovation of proven dependability, ready to go into service in a large system, take a long time and are very expensive. As a result, no single utility such as Ontario Hydro can afford to do a comprehensive range of development to meet all of its own problems. Therefore, the evolution of improvements such as those discussed above, from the stage of demonstrated technical feasibility to large-scale application in an operating system, proceeds on what must appear to the ordinary citizen to be a veritable geological time-scale.

The Socio-Economic Significance of Electric Power Policy

Clifford Alan Hooker

Clifford Alan Hooker has been a member of the philosophy department at the University of Western Ontario since 1970. He holds doctorates in both physics and philosophy and has written extensively on the philosophy of science and on environmental and social policies.

All social and economic activities require energy in one or more of its forms, so energy policy is fundamental to social and economic policy. My aim here is to put into perspective the great social and economic consequences that will inevitably follow from the decisions now facing us concerning energy – in Ontario, *electrical* energy primarily. The energy policy we choose now will have a profound effect on our way of life in the future, our standard of living, and our social freedoms. Moreover, for better or worse, we will be increasingly locked into whatever energy policy we select. So an understanding of the social and economic implications of energy policy is more important than any facts or figures about energy.

The Importance of Electricity

The importance of electrical energy to our life-style is obvious. Its flexibility, its compactness, and the precision with which it can be controlled make it highly attractive for home and industrial uses, and there are many purposes for which it is indispensable, such as communications. These two attributes of electrical energy – its attractiveness and its indispensability for certain purposes – explain why it brought its own miniature industrial revolution with it.

If we go back a century, we find the Industrial Revolution at its peak. Great factories and mighty steam engines were everywhere

in evidence, and steam trains thundered across the landscape carrying consumer goods. But a washing-machine, to do what a modern one does, would have needed a steam engine the size of a piano, and the engine's fire and pressure head would have needed to be maintained constantly. The machine would have had no timer, unless it had a cumbersome system of clock-and-gears. The whole device would have been large, hot, noisy, and expensive. The electrical dynamo and timer reduced all that to a motor the size of a football costing only a few dollars, a compact row of dials, and a switch. Electrical power has made possible a revolution in the white-collar application of power technology in the home, the office, and the school.

Still, washing-machines, however primitive, did exist a century ago. But there was no television, no radio, no telephones. Electrical power has transformed the structure of social communication and hence the nature of our society.

In some areas – heating and lighting, for example – alternative technologies were already well developed when electrical power arrived on the scene; it had to compete with them to win a place for itself. Many people alive today grew up in homes lighted by gas or oil lamps. Even today, domestic heating is still dominated by fossil fuels, though mainly gas and oil now, rather than coal. But, for lighting, electricity quickly overcame its rivals, because of its safety, quality, and flexibility from a design point of view. In space heating, where its advantages are less clear, electricity is only gradually increasing its share of the market.

Apart from those basic, everyday purposes, we find electricity powering a whole range of technological exotica: calculators, computers, lasers, Geiger counters, and a great variety of devices used in such installations as language laboratories, credit control systems, and nuclear missiles. Then there are the many electric industrial processes – for example, for the refinement of aluminum, the production of chlorine, electro-plating, and arc welding. So electric power has also brought about a transformation in the "blue-collar" industrial sector.

Many of the devices and processes I have mentioned could no doubt be designed for other forms of energy, though it is doubtful that they would be as attractive if they were. Many could not. The widespread use of electrical energy has undoubtedly transformed the structure of industry, and hence the texture of our lives. It has also transformed our social resources in a most dramatic way, especially our communications.

Electrical power is a fundamentally important form of energy in our society. That it is basic to us is only part of a broader truth: energy is fundamental to all vital processes, which are, at bottom, energy-conversion processes. A living organism is a thermodynamic device that converts chemical energy (food) into heat and movement, and this enables it to carry on its life processes. The pattern of biological energy transformations is closely duplicated in the pattern of our lives – and the same holds true for industry.

A machine is an energy converter. It converts, for example, electrical energy into movement, heat, or light. The pattern of industry is, first and foremost, the pattern of its energy flows and transformations. The scope of human technology is determined, basically, by the range of energy flows to which we have access.

Indeed, the history of civilization is, in a sense, the history of Man's increasing access to energy. When the nomadic life gave way to farming, more chemical energy (food) became available per capita, thus making possible the accumulation of the basic surplus of human energy on which urban civilization depends. Then, successive technological revolutions brought increased access to other sources of energy – the combustion of wood, and the harnessing of wind and water – and so laid the foundations of feudalism. After that came the Industrial Revolution, based on new technologies, such as steam power, and on the exploitation of limited, non-renewable energy sources – first coal, then oil and gas.

Now a new turning-point in this line of historical development looms. Fortunately, we have the technological capacity to develop alternative sources of energy. In evaluating these alternatives, we must remember that past energy transformations have had a profound impact on the evolution of our society. Energy policy is socially fundamental and must be formulated with great care. The relationship between technology and society is a two-way affair. Energy technology, as it developed, brought about important social and economic changes, and at the same time the economic and social interests of the day profoundly influenced the direction in which energy technology moved. This is well illustrated by the decline in the early part of the century of local, private facilities for generating electricity in favour of centralized utility companies. This happened because of overriding economic and political interests, even though it resulted in a decline in the over-all capacity for, and efficiency of, electrical generation. Similarly, the

nuclear power generator survived a development period of 25 years, during which it was not economically viable as a source of power, largely because of interests that were formed during World War II and sustained long after by the military importance of nuclear energy.

When we are assessing technological alternatives, then, it is important to remember that technologies are man-made, not God-given. They are made in the likeness of our values and habits. They reflect the way we choose to live – our economic and social structure. Choosing an energy policy means deciding to develop certain forms of energy technology. The decision is fundamentally a political and moral one.

Characteristics of Electricity

For all its merits, electrical energy is only one form of energy among many, and not always the best form for a given task. Our aim is to achieve some kind of socio-economic perspective on electrical power, and we must begin by analysing its characteristics, especially in relation to other forms of energy.

Energy can take many forms: heat, motion (kinetic energy), radiation, chemical, electrical, atomic, and configuration (potential energy). Each of these forms of energy has its own characteristics, positive and negative. Fossil fuels, for example, have the negative qualities of being non-renewable and of being polluting when burned to release their chemical energy; they also have positive characteristics: they are physically concentrated and so are relatively easy to store and transport.

Solar energy (radiation), in contrast, is indefinitely renewable and it is non-polluting to extract, which are positive characteristics, but it is also diffuse and difficult to store and to transport, which are negative characteristics. Before it can be stored and transported, solar energy must be transformed into some other form of energy, such as hydrogen gas, electricity, hot air, or hot water.

The transformation of energy from one form into another always involves some loss, and so is more or less inefficient. Some energy transformation processes are more wasteful than others.

Energy can be graded according to the kinds and amounts of useful work we can extract from it. For example, 1,000 joules – just under one British Thermal Unit – of heat energy at 5,000°C can be

used for all kinds of purposes, including welding, smelting metals, baking ceramic wares, boiling water, generating electricity, and heating homes. But 1,000 joules of heat at 10°C cannot be used for any of those purposes.

Generally speaking, the transformation of energy down to a lower grade can be made relatively efficiently, compared with the transformation of energy up to a higher grade. When energy is being down-graded, the efficiency of the transformation increases with the size of the gap between the grades. Conversely, when energy is being up-graded, the efficiency decreases as the gap between grades increases. The process of photosynthesis, which converts solar energy into chemical energy in green plants and represents a substantial step upwards in grade, proceeds with low efficiency (less than 5 per cent in most cases) while the conversion of chemical energy into low-grade heat (at, say, 100°C) is much more efficient (roughly 99 per cent).

Electrical energy is a relatively high-grade form of energy. Consequently, its production from other forms of energy – for example, by burning coal to boil water to generate steam to turn a turbine – is relatively inefficient. And since electricity does not occur naturally in large, accessible quantities, we have no choice but to produce it in some such inefficient way.

To summarize the salient characteristics of electricity:

Positive: high-grade
flexible to use
permits socially important and attractively designed technologies
relatively non-polluting to use

Negative: inefficient to produce
polluting to produce, if derived from most conventional sources (fossil, nuclear); much less polluting if derived from hydrodynamic, solar, wind, or biological sources
difficult to store in quantity
inefficient to transport via transmission lines
difficult to transport efficiently in stored form

The over-all level of use of electrical energy in a society always represents a compromise – a trade-off among competing forms of energy according to their abundance, cost of production, and technological usefulness, and according to the social consequences, or side-effects, of their use. The trade-off that is finally

arrived at is strongly influenced, not only by narrowly technological and economic considerations, but also by social and economic forces and vested interests, and by cultural values.

The side-effects of the use of electrical power today include:

1. the potential hazards of the production technology, e.g., in nuclear generators;
2. pollution caused by the production process;
3. the allocation of land for, and the environmental impact of, transmission lines;
4. the enormous investment required to expand the electrical system; and
5. the inhibiting effect of technology and social planning on local innovation and choice, and public participation.

The Side-effects of Energy Systems

Our society is continually being forced to compromise between these factors. The institutional processes by which we make the choices, and the actual choices we make, are both powerful reflections of the kind of life we aspire to.

At one time, the only factors seriously considered in the decision-making process were abundance of supply, cost of production, and technological usefulness. Decision-making in energy matters was done largely by individual private companies, each pursuing its own interest in the marketplace. Ontario Hydro, although it is a public utility pursuing a public mandate, has apparently operated in this fashion in the past. But times are changing, and today the side-effects of energy policies are getting more and more attention from the public.

Any analysis of electrical power planning, especially with respect to the side-effects, must begin with consideration of the total energy system. This is so because some of the most important trade-offs in the working out of energy policy are trade-offs among forms of energy. While it may suffice, for practical, day-to-day purposes, to consider electrical energy separately from the total pattern of energy production and use in our society, when it comes to long-term energy policy the total energy flow must be taken into account.

Indeed, the increasing importance of the side-effects of our energy system brings the following lesson home to us: When

long-term social policy is at issue, it is wisest to resist any inclination to separate energy from the rest of the fabric of society or to treat it as an independent commodity. We only need to recall the way almost all of our other social decisions ultimately affect the pattern of our use of energy to realize that policy-making for energy is intimately bound up with every other important feature of our society.

Consider, for example, how the increasing height of buildings in the centres of our cities leads to ever-greater consumption of electricity for heating, air-conditioning, and elevators – or the way the interior design of those buildings depends increasingly on artificial lighting. And add to this the way the ready availability of all these fixtures and appliances leads to an increasing demand for them, by encouraging habits that take them for granted.

My conclusion from these considerations is that, if we want to achieve a certain kind and quality of life, then we must plan for it in an all-round way, adapting our energy system and technologies to that end. The increasingly important side-effects of energy systems confront us with these twin challenges: (a) how to devise and set in motion the institutional means to plan effectively for our energy needs, and (b) how at the same time to avoid both financial bankruptcy and social stagnation – the alienation and loss of personal freedom that so often accompany the rise of powerful, centralized bureaucracies (in this case, the energy bureaucracies, both public and private).

I also see in this situation the same challenging and threatening elements that I see in all of our socio-economic problems: depletion of resources, pollution, urban blight, technological alienation, poverty – all pushing us towards systematic economic and social integration and away from expansive, individualistic culture.

Two Contrasting Scenarios

Let us imagine two very different responses our society might make to these challenges. At one extreme might be a policy of retaining the existing, strongly individualistic, competitive market system, in which the costs of economic competition, including those of all of the side-effects we have discussed, are allowed to accumulate as they may. Many people believe that in that direction lies a worsening of our social condition. It is worth noting here that

our society has often chosen to modify the operation of the market (by means of taxes, tariffs, regulations, unions, and so on) when faced with negative collective consequences.

At the other extreme we can visualize a policy of erecting a gigantic state bureaucracy to dictate exactly how everything shall be done. A great many people find this extreme repugnant.

The fundamental challenge in all of our socio-economic problems is to devise a humanly optimal course between the two extremes. The need for a new energy policy is an excellent case in point.

Now I want to describe and compare two alternative energy "scenarios" for Ontario's future. The first of these I shall call the *Conventional Scenario* (CS). It is arrived at by extending current energy trends into the future. Broadly, it reflects current thinking both at Ontario Hydro and in the Ontario and federal governments, as revealed in documents cited at the end of this paper. I must add, in fairness to our governments, that their thinking was changing in 1976, slowly becoming more sympathetic to at least some elements of the second scenario, which I shall call the *Localized, Low-technology, Low-environmental-impact, Conserver Scenario* (LLLCS).

The Conventional Scenario

The demand for electrical power is increasing by about 7 per cent annually and the over-all use of energy is increasing by about 5 per cent annually – both unprecedented rates. The increasing demand reflects not only the growth of the population and of the economy but also the continuing shift towards an all-electric-energy economy. It also reflects the continuation of certain social practices – in building design, for example. Buildings continue to be erected that are relatively poorly insulated for our climate and of heights that mean great losses of heat and expenditures of energy on elevators.

To meet the growing demand for electrical energy, it has been proposed that we should build in Ontario by the year 2000 something like 70 nuclear generators, with supporting technology (roughly five heavy-water plants as well as uranium mines and processing plants, storage facilities for waste, and so on). These generators would be in groups at roughly 12 sites, mostly in

southern Ontario. There would also be a substantial further investment in fossil-fuelled electric generators – roughly 26 units, grouped at seven sites.

Very-high-voltage (230,000-500,000 volt) transmission lines would form an energy grid criss-crossing the province from north to south and from east to west. By the year 2000, the great majority of people would be living within 25 miles of an electrical generator complex or transmission line, or would have to pass daily under a transmission line. Accumulated nuclear waste, by the year 2000, would amount to about 143,000 tons, and this waste would have to be stored somewhere indefinitely.

To put this energy system into operation would take an investment of about $40 billion over a 25-year period, according to present estimates, which might well escalate by three or four times before the work was done. As a matter of fact, in the three-year period 1973-6, the projected 15-year energy budget for Canada, under something like our conventional scenario, increased from $100 billion to $180 billion.

The electrical system is only one part of the over-all energy system. There would also have to be continued, massive investments in exploration for and exploitation of fossil-fuel deposits, and these investments would be even greater than those for the electrical system, according to present forecasts.

Some idea of the over-all nature of the CS may be gained by examining Diagram A and Diagram B of Figure 1, and comparing them. Diagram A shows the sources of the energy at present being used in Ontario, and where the electrical part of the total comes from. Diagram B is a forecast based on the CS of the sources of energy that will be used in Ontario in the year 2000, again indicating the sources of the electrical component. The pie in Diagram B is larger than the pie in Diagram A, reflecting the growth in demand that has been predicted by various government agencies and private consultants. Diagram A is based on 1973 statistics, but preliminary figures for 1974 and 1975 were similar.

About 30 per cent of energy currently consumed is electrical energy. The rest comes basically from fossil fuels (coal, oil, and gas). About 60 per cent of the energy derived from fossil fuels is used for low- and intermediate-grade heating (temperatures of up to 140°C) in one form or another. Most of the rest is used for transportation. Heating also takes about 25 per cent of the electrical energy consumed.

In the year 2000, according to the CS (Diagram B), electricity will

Diagram A

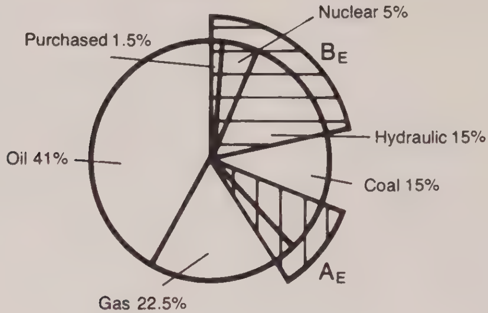


Diagram B

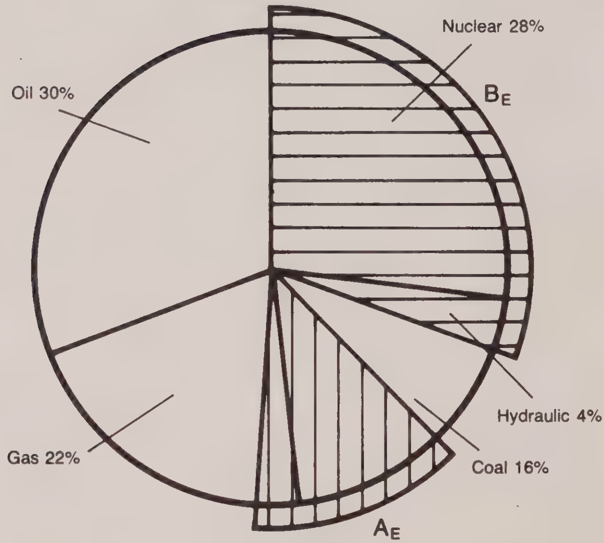


Diagram C

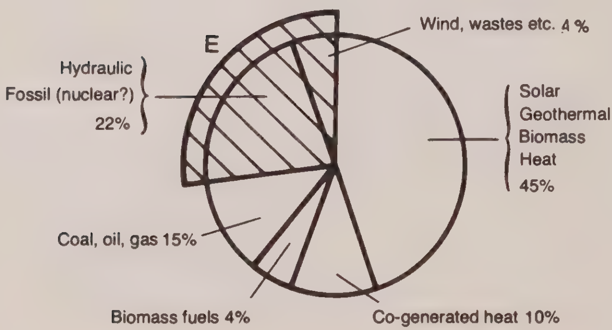


Figure 1. Sources of energy consumed in Ontario, and sources of the electrical component, 1973 and two scenarios for 2000 (percentages of total consumption).

Diagram A: 1973
(Source: Ontario Ministry of Energy)
Total energy consumption
2.8×10^{18} J *or* 2.7×10^{15} BTU
Electrical portion ($A_E + B_E$): 30.5 per cent

Diagram B: 2000 — "Conventional Scenario"
(Based on predictions by various government agencies and private consultants, as summarized by D. W. Ross and Associates Limited)
Total energy consumption
10.0×10^{18} J *or* 9.5×10^{15} BTU
Electrical portion ($A_E + B_E$): 44 per cent

Diagram C: 2000 – "Localized, Low-technology, Low-environmental-impact, Conserver Scenario"
(Based on the general features of energy demand and on the indefinitely renewable character of the natural low-grade sources of energy, and incorporating information from various sources on conservation and alternative technologies)
Total energy consumption
4.75×10^{18} J *or* 4.5×10^{15} BTU
Electrical portion (E): 26 per cent

Note:
The quantitative construction of the energy pies shown relates to primary energy consumption (basis 1 kilowatt-hour equals 10,000 BTU or 10,550,000 J). When we talk of *using* electricity, it is useful to think of 1 kilowatt-hour being equivalent to about 3,412 BTU. Only very small losses occur, and conversion of electricity to other forms of energy (heat, mechanical motion, etc.) is nearly 100 per cent efficient. However, a thermal generating station, for the production of 1 kilowatt-hour of electricity, consumes more than 3,412 BTU. In fact, the production of 1 kilowatt-hour requires almost 10,000 BTU. One can see from this that the production process is only about 35 per cent efficient; two-thirds of the energy output from a thermal power station may be termed "waste heat".

This difference in conversion efficiencies between end use and production alludes to the difference in usefulness between various forms of energy. All three diagrams ignore this difference. Our future energy sources and energy conversion technologies are, of course, very uncertain, and the speculative nature of Diagrams B and C must be emphasized.

be about 44 per cent of the total energy consumption, and 65 per cent of the electricity will be nuclear-generated. Intermediate- and low-grade heating will account for about 50 per cent of all energy used and for about 45 per cent of all electricity used, reflecting the switch to electrical heating. Since electricity cannot be produced or transmitted very efficiently, Diagram B represents a decline in efficiency from Diagram A – an increased loss of heat to the environment.

The Localized, Low-technology, Low-environmental-impact, Conserver Scenario

Three strategies govern the choice of energy systems, in this scenario:

1. Wherever possible, reduce the demand for energy by changing current practices and technology, provided that the (monetary and social) costs are not unreasonable.
2. Make the greatest possible use of locally available energy, and match the grade of energy to the grade of use.
3. Develop energy technologies in local, decentralized forms, whenever this is consistent with (1) and (2).

Strategy 1 implies conservation measures. Where possible, energy-intensive industrial processes are redesigned to reduce consumption. Buildings are redesigned so that they can be more efficiently heated and cooled, forms of transportation are chosen that are more efficient than the automobile, especially for large cities – and so on.

It has now been reported in a number of major studies that the demand for energy could be reduced by roughly 30 per cent, without seriously affecting the style of our lives, by the introduction of some simple conservation measures, and that it could be reduced by about 60 per cent by adopting some more serious but still quite feasible changes.

Strategy 2 implies a major move away from fossil fuel and non-hydraulic electrical power as sources of bulk energy, in the direction of solar, geothermal, and biomass energy, with wind

energy also in the picture. The ideas behind this are simple. In the first place, roughly half of our energy requirements are for low-grade heat. Solar and geothermal energy are abundant and indefinitely renewable sources of low-grade heat. Moreover, the heat can be extracted in a relatively pollution-free and safe fashion, with little or no environmental impact. Secondly, other sources of energy that occur naturally, particularly hydraulic, biomass, and wind energy, are attractive because they, too, are indefinitely renewable, clean, and safe to extract.

Biomass energy (from plant material and biological wastes) also happens to be abundant. It has been estimated, for example, that the pulp and paper industry, Ontario's biggest consumer of electricity, could become self-sufficient for energy by using its own wastes properly. And forests in Ontario that are at present considered non-economic, together with other sources of biological materials, could yield enough ethanol and methanol to supply one-third of the energy needed for transportation in Ontario.

Hydraulic energy is abundant in Ontario and is already being used, though not to the fullest possible extent. And wind energy, while not abundant, can be used as a safe and clean supplement to the other forms.

Diagram C in Figure 1 shows what the situation might be in the year 2000 as a result of following these two strategies. The pie in Diagram C is only slightly larger than the one in Diagram A, indicating that the total amount of energy used has not increased much in the interval. Diagram C indicates a smaller role for fossil fuels than Diagram A or Diagram B, and a smaller role for electricity than Diagram B. Both of these forms of energy are now (Diagram C) used mainly for purposes other than heating, each for what it is best suited for: fossil fuels for some transportation, electricity for the essential purposes mentioned earlier and increasingly for public transportation.

The LLLCS future is largely, perhaps entirely, non-nuclear. Instead of massive nuclear energy plants and transmission grids there would be millions of small, on-site heating plants, and thousands of small electrical generators yielding both electricity and heat for local use – together with a modest centralized electrical system of roughly the present dimensions, run from existing hydraulic plants.

The LLLCS would ensure that the advantages of decentralized technology for energy were fully exploited. But the main advantages would be socio-economic ones.

The Relative Costs

The two very different energy futures I have described are not, of course, the only possible ones. I have presented these two scenarios so that I will be able to compare them and so, I hope, illustrate in specific terms the great social and economic importance of energy choices. It will remain then for the public to debate the full range of alternatives.

It is difficult to say which of the two scenarios would be the more costly in the short term, from a gross economic point of view. But there is reason to believe that the LLLCS would be substantially cheaper in the long run. For example, the installation of a solar heating unit does not compare favourably, when judged on immediate installation costs in the year of installation, with the alternative of carrying on with oil or electric heating. Indeed, the conventional forms of heating will probably continue to have a slight economic advantage even when costs are averaged over 10 years. Over a 25-year period, both scenarios would involve investments to renew technology, but, even so, somewhere in the 15-25-year period after installation, the LLLCS would begin to appear more attractive.

In the longer term, say 50 years, the advantage would lie increasingly with the LLLCS. The CS faces uncertainty concerning the supply of oil, gas, and uranium, and rapidly escalating prices for those fuels. In contrast, the LLLCS could look forward to steady improvements of technology and would be based on indefinitely renewable forms of energy. It would involve the use of fossil fuels, but on a decreasing scale, which would tend to ease the price squeeze and the risk involved in any dependence on foreign supplies.

This is strikingly demonstrated by a 1976 federal government position paper entitled *An Energy Strategy for Canada*. This paper contains a conservative estimate that a scenario something like the CS would cost Canadians $180 billion over the next 15 years, and perhaps $350 billion over the 25-year period ending in 2000. And at that point Canada would be left with huge foreign debts and a current trading deficit, and would be in the position of having to depend on large oil imports. Apart from that, the country would be no nearer than it is today to a long-term solution of its energy problems. In contrast, the expenditure of the same amount of money on the LLLCS should suffice to put in place the technology

and institutions that would provide a secure, long-term energy future.

On the other hand, the CS is based on a technology that is very probably capable of delivering the energy that will be demanded. There is no doubt that, from a purely technical and conventional economic point of view, Ontario Hydro has one of the world's best performance records for a utility company and that, if we are willing to pay the costs (both economic and social), the CS can be realized as planned.

Whatever the pros and cons may be, consideration of the two scenarios reinforces the impression that, over the next 25 years, the people of Ontario will have to make massive investments in energy and energy technology. Finding the necessary capital is going to place a considerable strain on the resources of the province, as indicated by the government's insistence in 1976 on cutting $6.4 billion from Ontario Hydro's projected $35 billion, 10-year budget. And it was made clear that, even with such a cut, difficulties were envisaged in financing the program beyond 1982.

Clearly, any alternative plan that holds out the prospect of substantial savings, as the LLLCS does, should be looked at carefully. Otherwise we may well find ourselves pursuing not the CS but whatever cut-down version of it we can afford. At the same time, we must examine carefully the social consequences of these massive investments, to establish which is the most desirable energy path from that point of view.

The Social Implications

Serious as the economic issues are, they are outweighed in importance by the wider social implications of the choice we must make of an energy system for the future.

Consider first the basic differences in technology between the two scenarios that I have described. Under the CS, we would make massive social investments in nuclear technology, high-voltage transmission technology, oil refineries, etc. This, in turn, would mean investments in land, skilled personnel, uranium-mining equipment, etc. Certain parts of the community would benefit greatly from these developments while others would simply help to pay the bills. The same would hold true to some extent in the LLLCS, but, generally, different parts of the

community would benefit, because the technological investment would be in the field of smaller-scale engineering. There would be little need for uranium mining and most of the skilled workers required would be plumbers and mechanics rather than the highly skilled construction crews and nuclear technologists called for by the CS.

As we examine the two scenarios in terms of their expected social impact, two important differences emerge clearly:

1. The LLLCS would probably distribute the capital investment more evenly than the CS, both in geographical terms and industry by industry. Virtually all of the thousands of small firms in the province would share in the development. The CS would involve only a few large organizations for its massive, highly specialized technology. The energy field would thus become a new monopoly, concentrating the publicly invested wealth in the hands of a few large firms (many of them not Canadian-controlled).
2. The massive electrical technology called for by the CS would concentrate the jobs in the ranks of the highly skilled few. Conventional technology is highly capital-intensive; for an investment of several billion dollars, we would acquire a nuclear plant that took 2-5 years to build, involved a crew of only a few thousand, and required a permanent staff of only about 1,000 to operate. In contrast, the designing, construction, and maintenance of the simpler but much more numerous plants of the LLLCS would provide continuing employment for far more people than the CS. Moreover, employment in the LLLCS would be mainly in trades that are easily accessible to everyone, and the challenge to adapt each plant to the requirements of the home or factory it was to serve would encourage innovation and stimulate interest in the job.

The new technologies that would be required for a scenario such as the LLLCS might, of course, come under the control of industrial giants, with all of the consequences that would produce. Also, the new technologies could be developed in a centralized fashion (for example, vast solar farms generating electricity for the familiar transmission grid), thereby reproducing a characteristic of the CS. There is nothing in the new technologies themselves to determine the manner in which they will be developed, but they do not preclude decentralized development, as the CS does.

Whether any of the alternative technologies are adopted at all, and whether, if they are adopted, they will be developed in a decentralized way as in the LLLCS, will depend on political decisions, and on the public to the extent that it is able to influence those decisions.

Options for the Future

Next, consider the question of energy options for the future. No matter what scenario we choose, the very size of the investment that will be required will provide a powerful reason for continuing to pursue it, even if it begins to have negative social consequences. Other kinds of investment will be required, apart from money. The trades that will be in demand will differ according to the scenario, but no matter what scenario we choose there will be massive demands for skilled trades of kinds that cannot be supplied from the existing labour force. And, once people are trained in new trades and dependent on them for a living, there will be strong pressure to continue to develop the energy system that supports them.

Note also that many courses that are being pursued in our society in fields other than energy will have major effects on our energy plans. I have already mentioned the sprouting of high buildings in our cities. Another example is the increasingly energy-intensive farming, involving more mechanization and greater use of fertilizers and pesticides. On the other hand, the appeal of such practices is determined increasingly by the cost of energy.

The upshot of these considerations is that the choice of an energy policy is really a fundamental part of the choice of a social policy – a way of life – and in the future we will be increasingly locked into the energy policy we choose, because of all the other decisions that depend on it. So it is important to think very carefully now, when there are still some real options open to us, about the way of life we want to pursue. Moreover, it will be important to try to choose an energy policy that leaves some options open as long as possible.

In this connection, the massive, centralized technology of the CS clearly leaves us fewer future energy options than the decentralized, small-scale technology of the LLLCS. The large investment implied by the CS could not be abandoned easily, nor could the other social processes that depend on electricity (e.g., the vertical rise of city cores) be easily reversed. It seems reasonable to suggest that the LLLCS is likely to offer considerable flexibility of choice in the future, because of its relatively low level of technology and its diversified energy system. Under the LLLCS, perhaps, each household and business would have a sum of money invested in heating technology, a similar sum invested in electrical apparatus, and another sum invested in fossil or biomass fuel technology

(e.g., for motor vehicles). The balance between the investments could be altered over the years as economic conditions changed and technology developed. And, since the social investment in any one technology (e.g., electrical generators) would be relatively small, it would be relatively easy to make changes, should that become necessary.

The element of reliability also varies between scenarios. A centralized energy system purchases reliability through excess generating capacity that can be brought into use in the event of a failure. This increases the cost of the system. A decentralized system would forego any over-all back-up system but would limit the effect of any one failure to those people in the immediate locality. (Local back-up systems would, of course, be possible, but they would increase the cost of the system. The chosen "mix" would be a social decision.)

The Two Scenarios Further Compared

The two scenarios we are considering have different implications for the diversification of energy sources.

Centralized energy systems could control regional development, if the government of the day so desired, simply by withholding electrical power from some regions and supplying it to others, or through pricing. On the other hand, a centralized power system could promote regional freedom of choice by making an abundant supply of electricity available from a power grid, leaving each region free to decide how to use the supply. This situation obtains today in southern Ontario, but not in the north, where the policies for developing the centralized network have an important impact on the total pattern of development.

A decentralized, mixed-technology energy system would allow scope for local and regional innovation, without need of excess generating capacity. Individual homes and businesses would, in general, meet their own energy requirements by means of plants designed individually for them. Collective regional energy requirements (of high-voltage electrical power, for example) could be met by varying combinations of technologies suited to each region – hydro-electric in some regions, and coal-fired plants or a

combination of wind and methane generators in others. Regional planning could be largely decentralized and left up to the regions and the individuals within them.

Finally, we come to the question of the broadly political and cultural implications of the alternative energy systems we have been considering. The choice between the CS and the LLLCS might be considered a choice between the further reinforcement of the existing, centralized bureaucracy with its monopoly on electrical power development, on the one hand, and the creation of a system of decentralized energy planning centres and energy technology industries, on the other. The choice will depend on the importance we attach to effective public control of energy policy. Whatever is decided will have an impact on our social freedoms.

There is a strong tendency in any society to respond to difficulty or crisis by appealing to some central authority. Our economics reinforces this tendency by prescribing centralized consolidation as the path to greater efficiency. Also, centralized institutions bring with them a potential for centralized social control. We have key institutions that control the direction of future developments in energy, communications, education, health, and transportation. Of these, energy is the most fundamental.

To avoid the adverse social consequences of continuing to develop a massive, centralized energy system would involve, at the very least, the creation of some quite new institutions capable of controlling the technical development of the system in a rational fashion while opening up the decision-making process to effective public participation. Anyone who has bureaucratic experience knows how difficult that would be.

On the other hand, the decentralized, mixed-energy technology of the LLLCS would permit a high degree of individual initiative and regional choice. Physical decentralization of the basic stuff of all life processes could be part of a general decentralization of social control. There is, of course, no guarantee that this would happen except as a result of a deliberate political decision. Nor should it be imagined that the decentralized scenario would necessarily mean freedom from central decision-making. To begin with, strong conservation measures would surely require strong collective decisions, backed up by the power to enforce them. Similarly, for the effective implementation of new energy designs, everyone would have to accept them. Only within a framework of collective restraint is greater individual freedom of choice possible. On the other hand, the greater use of local, naturally occurring energy

sources in the LLLCS, compared with the CS, would mean that some collective decisions could be left to each region, which would be free to follow any path that did not adversely affect other regions.

Provincial energy policy-making would remain essential in the LLLCS, but there would be two significant differences, in this respect, from the CS:

1. Policies would be more concerned with co-ordination, community design, and the pattern of province-wide development than with the details of the energy system itself. This would be less true of the refined fossil fuels (supplying roughly 17 per cent of the energy used) than of electric power (roughly 25 per cent) because the reduced over-all demand would mean greater flexibility in the choice of technology. By and large, the initiative for energy-supply technology would be left to the regions and to the individual enterprises within them. In short, provincial energy policy would become true political policy, concerned with the human values that determine the quality of community life.
2. In the LLLCS, provincial policy would reflect the policies of the regions much more strongly than in the CS. It would be natural to regionalize provincial energy institutions, including Ontario Hydro, and to constitute the central provincial policy-making bodies from elected regional representatives, with a small central secretariat.

National energy accounting and resources policy would remain important, but, like provincial policy-making, it would be concerned primarily with decisions affecting the over-all nature of our society and the management of that (much reduced) part of the energy budget that would be produced in other provinces or outside the country.

In the LLLCS, Ontario would play an important role in a cultural movement away from bigness and towards a combination of small-scale community and political co-ordination. Thus, the CS and the LLLCS attach themselves naturally to two sharply contrasting social movements.

Two Concepts of Human Existence

As already noted, the energy system in Ontario was allowed to develop more or less the way individual institutional interests dictated. Only in the last decade have governments taken any

serious, sustained interest in long-term energy policy. There have been issues connected with fossil-fuel supply that occasioned public debate, and gas pricing has been regulated for some time, but nothing like an energy policy has evolved. Only in the last few years has Ontario had an integrated Ministry of Energy, and already in that short time there have been many important developments. The hitherto unquestioned oil company estimates of Canadian oil and gas reserves have been slashed by two-thirds; the price of oil and gas, both Canadian and imported, has risen sharply; and the cost of Ontario Hydro's generation program has, for the first time, become a strain on the province.

The government has responded to these developments by creating a succession of new energy policy institutions. The Ontario Energy Board emerged in 1973 out of the old Ontario Fuel Board, with responsibility for reviewing economic decisions, especially concerning rates. In the same year, Task Force Hydro was created to review the development and the future of Ontario Hydro. Closely following that, and on the heels of the Middle East crisis, the Ministry of Energy and the Ontario Energy Corporation were created – the first to integrate provincial energy policies, the second to take an active financial interest in Ontario's energy future, with emphasis on the securing of fossil-fuel supplies. The same period saw the creation of the Cabinet Committee on Resources Development and other, similar, cabinet super-committees – reflecting, I believe, a growing realization on the part of the government that energy policies can only be pursued meaningfully "in the whole" – in a comprehensive, integrated way.

Clearly, we have now reached that moment in history when we can no longer evade the responsibility to create public policy-making institutions that will be capable of planning an effective, all-embracing policy while as far as possible preserving our freedom with regard to energy, technology, and society in general. In this historical context, we can see the only important and enduring contribution the Royal Commission on Electric Power Planning can make: it must help us to bring the wide economic and social ramifications of energy policy-making clearly and decisively into the realm of public discussion.

The economic and social differences between the two energy scenarios I have described are great. The scenarios apply different technologies to achieve different energy systems based on different sources of energy. Their likely impact on industry, employment,

and regional development would be very different, as would their effect on our future freedom of choice in energy matters. Finally, the two scenarios belong to different historical currents in our culture, and they support different conceptions of the nature and purposes of human existence. So much and more is bound up in policy-making for energy – and, therefore, in electric power planning.

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